

Water Resources Assessment of Sabarmati River Basin, India

A document to analyse the future scenarios of a water-deficit basin
as support to country water policies

Country Policy Support Programme (CPSP)

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**INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE (ICID)
NEW DELHI**

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International Commission on Irrigation and Drainage (ICID) was established in 1950 as a Scientific, Technical, Non-commercial, Non-Governmental International Organisation (NGO) with headquarters at New Delhi, India. The Commission is dedicated to enhancing the worldwide supply of food and fiber by improving water and land management, especially the productivity of irrigated and drained lands. The mission of ICID is to stimulate and promote the development and application of the arts, sciences and techniques of engineering, agriculture, economics, ecological and social sciences in managing water and land resources for irrigation, drainage and flood management using research and development, and capacity building. ICID aims to achieve sustainable irrigated agriculture through integrated water resources development and management (IWRDM). ICID network spreads to 104 countries all over the world.

Country Policy Support Programme (CPSP) was launched by ICID in 2002 to contribute to develop effective options for water resources development and management to achieve an acceptable food security level and sustainable rural development. The programme is implemented in five countries viz. China, India, Egypt, Mexico and Pakistan and is funded by Sustainable Economic Development Department, National Policy Environment Division, The Govt. of The Netherlands as Activity No. WW138714/DDE0014311.

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EXECUTIVE SUMMARY

Background

The World Water Vision on Water for Food and Rural Development (WFFRD) for year 2025, formulated through extensive consultations held in over 43 countries, was facilitated by International Commission on Irrigation and Drainage (ICID) and a few other International Organisations. The theme document presented at the 2nd World Water Forum in The Hague in 2000 projected a substantial increase in the global water withdrawal, water storage and irrigation expansion for the pre-dominant “food sector”. (largely consumptive). A majority of these projections of large increases related to the developing countries. However, the integrated overview Water Vision document scaled down these requirements in an attempt to consolidate conclusions and recommendations of various other themes. It also did not reflect quantification of water needs for the “people sector” (largely non-consumptive) and the “nature sector”.

In order to analyse the supply and demand issues of all the three sectors, namely food, people and nature in an integrated manner, ICID initiated a ‘Strategy for Implementation of Sector Vision on Water for Food and Rural Development’ initiative in the year 2000. ICID also felt the need to mobilise strong international support for strategies and policies in water sector to achieve food security and reduce poverty in developing countries through independent water assessments. In line with this, ICID launched a project titled “Country Policy Support Programme (CPSP)”, with a funding support from the Government of The Netherlands.

China, Egypt, India, Mexico and Pakistan having 43% of the world population and 51% of the world irrigated areas were chosen as participating countries in the CPSP. To begin with, detailed assessments were planned and implemented for the selected sample basins for the two most populous countries of the world, viz.; China and India considering their population growth and rate of urbanisation which factors have strong bearing on water demands. Multi-stakeholder consultations at the respective basins and national level, were held to discuss the outcome of detailed assessments, including extrapolation to country level and findings from such consultations were used to

identify elements in the national policies requiring changes in the context of integrated and sustainable use of this vital natural resource. This experience in assessments was to be used for a similar exercise at a lesser scale in the remaining three countries.

To capture the major issues of typical basins through detailed assessments in India, a water-deficit basin namely the Sabarmati river basin on the west coast, and a water-rich basin namely the Brahmani river basin on the east coast, were chosen. A simplified but a more broad based, comprehensive modelling approach was adopted keeping the CPSP goals in mind. This model, called ‘Basin-wide Holistic Integrated Water Assessment’ (BHIWA) was evolved to address the following objectives:

1. To consider the impact of changing land and water use on the resources, taking into account interdependencies between different elements of the land phase of the hydrological cycle,
2. To quantify and integrate sectoral water uses, and
3. To formulate and analyse scenarios in order to evaluate various policy options for development and management of water and related land resources.

The model can be used effectively for the following purposes:

- (a) Understanding resources and sectoral needs in an integrated manner considering sustainability of water for human use as well as for environment, and
- (b) Creating and improving knowledge base for meaningful and transparent dialogue.

The model was calibrated based on data for present conditions and applied to identify main issues and challenges in basin water management through the analysis of alternate scenarios of future (year 2025). The results of these assessments for the two basins, including their extrapolation to other major basins and policy related issues emerging from the comprehensive analyses were presented in a National Consultation held in November 2003, at New Delhi. Subsequently, two more river basins in India –

Tapi on the west coast and Pennar on the south east coast – were selected for similar assessments in order to have a larger regional representation.

This report covers the detailed assessment of Sabarmati river basin in India through application of BHIWA model. Initial basin level consultations were held based on preliminary analyses and contributed in large measure primarily in collection of the available data and information from a host of organisations. The approach also helped in assessing the severity of the many problems that require approaches emphasizing equitable and sustainable management.

Overview of Sabarmati Basin

Sabarmati river is one of the major west flowing rivers of India. The basin drains an area of 21,565 km², of which 17,441 km² lies in the state of Gujarat and 4,124 km² in Rajasthan. The pseudo-natural mean annual runoff is estimated to be 3,810 million cubic metres corresponding to pre- 1960 conditions. With a relatively large population of 11.75 million in 2001, this gives a per capita availability of water of 324 cubic meters per person per annum, which is lowest among the basins of India. As a result of the rapid pace of socio-economic development, the demand for water has experienced a steady increase for irrigation as well as domestic and industrial use.

Agriculture is the dominant land use with forest and 'land not put to agriculture' use accounting for only about 42% of the basin area. The rain-fed and irrigated agriculture have almost equal share. The annual irrigation from existing major, medium and minor surface water projects* is presently of the order of 0.43 million ha. while that from groundwater through public, private tube wells and dug wells is roughly estimated to be a little over 0.70 million ha. Source-wise, ground water has a major share in terms of area under irrigated agriculture. The present level of irrigation has been made possible mainly through inter-basin transfer of surface waters from the adjacent Mahi river. Additional import from Narmada river has further augmented the supply and more imports are proposed by Gujarat State.

Large Industrial base and urbanisation has added to the water demands. There exist 20 industrial estates

developed by Gujarat State Industrial Development Corporation (GIDC), besides a sizeable number of private industries. There are two thermal power stations in the basin, one in Ahmedabad and another in Gandhinagar. There is a major fertilizer plant of IFFCO in Kalol, falling within the basin area. There is an ample scope and plans for further industrialisation in the basin. The urban population of the basin accounts for about 52 percent of the total as per the 2001 census, which is expected to grow in future and put extra demands for domestic use and sanitation. More than three- fourths of the urban population resides in Ahmedabad-Gandhinagar conglomerate and rise in living standards shall lead to further increase in water demand for Domestic and Industrial (D&I) use. Even at present, the basin is beset with problems of over-exploitation of groundwater, non-filling of surface water storages, deteriorating of both surface and groundwater quality, social in-equity and inter-sectoral conflicts.

Application of BHIWA Model

As a first step towards understanding of the basin water resources, including external imports and exports, the especially developed BHIWA model was applied to Sabarmati river basin. The basin was divided into three sub- basins to account for heterogeneity in physiography, rainfall and water use. The model was calibrated for the present (1995-2000) conditions of water infrastructure, land and crop water use in each of the sub-basins. The aggregated results confirmed that the groundwater use in the basin, being practiced currently, is unsustainable. The model was applied to derive responses to past (1960) conditions to establish an approximate baseline for low flows and estimate pre-development within the basin water potential. The Present (1995) situation was restudied to achieve sustainability in ground water use through additional surface water transport and induced recharge from river. Eight future plausible scenarios for 2025 were visualised. These considered to proposed plans, better water and soil management and likely extent and seasonal shifts in future agriculture water use including possible changes in land use. Propensity of the people in the basin to adapt to strategic changes and face compulsions was also kept in view. Apart from Business as Usual (B as U) scenario, following alternative future (2025) scenarios were examined:

* In India, the connotation of major, medium and minor irrigation projects is based on a categorization: Major: CCA (culturable command area) > 10000 ha, Medium: CCA> 2000 ha < 10,000 ha. and Minor: CCA<2000 ha.

- Irrigation expansion, but no Import of water from Narmada basin (worst case scenario);
- The current proposals of Gujarat Govt. for water infrastructure development including the pumping of Narmada waters in the upper reservoirs, and increase in amounts of in-basin use, imports and exports
- Lesser import and export of water;
- Irrigation expansion and agricultural seasonal shift;
- Reduction of groundwater use and in the pumping Narmada waters into the reservoirs; (as compared to the future plan of Gujarat)
- Reduction of groundwater use by lesser irrigation expansion and better management; and
- Limited agriculture shift and water exports.

The total water input in an average year (rainfall and imports) to the basin under the present (1995) situation amounts to 17,744 million cubic meters. The major outflows from the basins comprise of consumptive use or evapo-transpiration (ET), river flows and exports. The total consumptive use under present (1995) situation is estimated to be 14,796 million cubic meters, comprising about 35% by nature sector (forest, pasture and barren lands), 64% by agriculture sector (rain-fed and irrigated agriculture) and only about 1% by people sector (domestic and industrial). The “non-beneficial” component of evapo-transpiration works out as about 22% of the total evapo-transpiration. It is seen that out of total consumptive use of irrigated agriculture, almost 50% is met by rainfall and the balance supplemented through irrigation.

Summary of Findings

The major findings of the assessment made for Sabarmati basin are:

- Non-beneficial ET in the nature and agriculture sectors is of the same order as the annual river flow.
- Reduction of non-beneficial ET through appropriate soil and water management can be a potential strategy.
- Import of Narmada water is necessary to sustain the present withdrawals and to meet also the future

needs, including that for improvement of low flows to maintain river ecology.

- Quantum of the groundwater use at present is unsustainable. While the situation would improve slightly in future due to possible large addition on account of imports from Narmada, composition of return flow indicates much higher risk of groundwater pollution. This problem calls for large-scale artificial recharge to groundwater, or alternatively for a considerable reduction in groundwater and the total use.

Four indicators have been suggested to depict “water situation” in quantitative as well as qualitative terms. Two indicators depict the pressure on resources due to surface and groundwater withdrawals as a fraction of total water inputs to these two respective sources, while the other two indicators depict potential hazard to water quality in the surface and ground water systems based on fraction of returns.

Based on the suggested classifications, and derived values of indicators, the Sabarmati river basin falls in the category of “moderately stressed” through surface water withdrawals and “very highly stressed” through groundwater withdrawals. In terms of threat to water quality, it falls “moderate threat” category for its surface water, while it is in the category of “high alert” in terms of quality of its groundwater.

Policy Related Issues and Recommendations

The main policy related issues emerging from the Sabarmati river basin study are as follows:

- To account for direct evapo-transpiration from rainfall and soil moisture it is essential that precipitation (or rainfall), which forms the primary source of all waters on land, rather than the terrestrial surface and ground water runoff is to be recognised as the primary and real resource for water assessments.
- There is also the need for accounting of additional water availability due to return flows; and accounting of water withdrawals and consumptive use by sectors, separately and collectively towards an integrated and sustainable water management.
- The consumptive use, which results in the

depletion of resource, needs to be managed through increases in efficiencies across all sectoral uses, and by curtailing specially its “non-beneficial” component. .

- ❑ While local harvesting of rain can to some extent be promoted, its usefulness in water short basins like Sabarmati, where the existing reservoirs hardly fill up, is very limited as it impacts negatively on the filling of existing storages on the main river and its tributaries
- ❑ Inter-basin transfer of surface waters from adjacent river basin or basins is an obvious option to meet the additional needs of water deficit basins such as Sabarmati and to restore the groundwater regime and provide for environmental flows in the downstream.
- ❑ Inter-basin transfers, in the water short basins with considerable rural population, appear necessary to increase the economic carrying capacity of the basin, through increased income from the small landholdings.
- ❑ The high groundwater use needs to be curtailed as artificial recharge from imported water may be technically and economically unviable, besides threatening water quality and reducing dry season river flows.
- ❑ Better soil and water management through introduction of sprinkler and micro irrigations etc. would no doubt be of some help in demand management. But likely growth of irrigation and D&I demands in future dictate much larger

imports from outside basins in future. As mentioned earlier, this is also needed to restore the dry season flow in the vulnerable reaches and improve freshwater environment especially in the lower reaches of the rivers like Sabarmati.

- ❑ The increasing hazards of pollution of surface and ground waters, through higher proportion of return flows, needs to be countered both by adequate treatment of the wastewater being discharged into natural waters, and by encouraging reuse of wastewaters without discharging these in water bodies.
- ❑ Adjusting the cropping patterns to the availability of water, through a shift from post monsoon irrigation to monsoon irrigation, can reduce the consumptive use of water.
- ❑ The high priority given to the drinking water has to be elaborated by defining the core and non-core demands, and by allocating the better quality and more reliable sources to meet the core demand.
- ❑ Environmental water requirements need to include both the requirements (mostly consumptive) of the terrestrial eco-systems, as also the flow requirement (EFR) of the aquatic ecosystems. While environmental flow requirements (EFR) need to be recognised as valued requirements, acceptable methods (which consider the water regimes required by the different species, as also the tradeoffs, as preferred by the society, between the environmental and other uses), need to be developed.

ACRONYMS / ABBREVIATIONS

ASMO	Area Sown More than Once
B as U	Business As Usual
BHIWA	Basin-wide Holistic Integrated Water Assessment
CDO	Central Designs Organisation
CGWB	Central Ground Water Board
CPSP	Country Policy Support Programme
CWC	Central Water Commission
D&I	Domestic and Industrial
EFR	Environmental Flow Requirements
ET	Evapo-transpiration
ET _o	Reference evapo-transpiration
FAO	Food and Agriculture Organisation of United Nations
G&D	Gauge and Discharge
GCA	Gross Cropped Area
GIA	Gross Irrigated Area
GIDC	Gujarat Industrial Development Corporation
GOG	Government of Gujarat
GOI	Government of India
GW	Ground Water
GWP	Global Water Partnership
Ha or ha	Hectare
IAH	Indian Association of Hydrologists
ICID	International Commission on Irrigation and Drainage
IFFCO	Indian Farmers Fertilizer Corporation
IIT	Indian Institute of Technology
INCID	Indian National Committee on Irrigation and Drainage
IUCN	The World Conservation Union
IWMI	International Water Management Institute
IWRDM	Integrated Water Resources Development and Management
Km	Kilometer
MAR	Mean Annual Runoff
MOWR	Ministry of Water Resources
NGO	Non Governmental Organisation
NIA	Net Irrigated Area
NSA	Net Sown Area
NWP	National Water Policy
SB	Sub-Basin
SW	Surface Water
WAPCOS	Water & Power Consultancy Services (I) Ltd.
WFFRD	Water For Food and Rural Development
WR	Water Resources
WWF	World Wide Fund for Nature

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CHAPTER 1

SABARMATI RIVER BASIN

1.0 Introduction

1.0.1 Background to CPSP

The World Water Vision on *Water for Food and Rural Development* (WFFRD) for year 2025, formulated through extensive consultations held in over 43 countries, was facilitated by International Commission on Irrigation and Drainage (ICID) and a few other International Organisations. The theme document presented at the 2nd World Water Forum in The Hague in 2000 projected a substantial increase in the global water withdrawal, water storage and irrigation expansion for the pre-dominant “*food sector*”. (largely consumptive). A majority of these projections of large increases related to the developing countries. However, the integrated overview Water Vision Document scaled down these requirements in an attempt to consolidate conclusions and recommendation of various other themes. It also did not reflect quantification of water needs for the “*people sector*” (largely non-consumptive) and the “*nature sector*”. Water needs of the food sector depend on the population, the changing dietary preferences and the income levels. Likewise, the water needs of the people sector also depend, apart from population, on the quality of life, income levels and the general economic growth including the industrial growth. The water needs of the nature sector, including the need of the terrestrial and aquatic eco-systems depend on the land use as also on the preferences of the society in trade offs between the uses and ‘non-use’ of water.

In order to analyse the supply and demand issues of all the three sectors, namely food, people and nature in an integrated manner, ICID initiated a ‘Strategy for Implementation of Sector Vision on Water for Food and Rural Development’ initiative in the year 2000. ICID also felt the need to mobilise strong international support for

strategies and policies in water sector to achieve food security and reduce poverty in developing countries through independent water assessments. In line with this, ICID launched a project titled “Country Policy Support Programme (CPSP)”, with a funding support from the Government of The Netherlands.

China, Egypt, India, Mexico and Pakistan having 43% of the world population and 51% of the world irrigated areas were chosen as participating countries in the CPSP. . To begin with, detailed assessments were planned and implemented for the selected sample basins for the two most populous countries of the world, viz.; China and India considering their population growth and rate of urbanisation which factors have strong bearing on water demands. Multi-stakeholder consultations at the respective basins and national level, were held to discuss the outcome of detailed assessments, including extrapolation to country level and findings from such consultations were used to identify elements in the national policies requiring changes in the context of integrated and sustainable use of this vital natural resource. This experience in assessments was to be used for a similar exercise at a lesser scale in the remaining three countries.

As a first major step towards this initiative detailed water assessments for the past, present and future conditions were taken up for, two sample river basins in India namely Sabarmati river basin, which is a water deficit basin on the west coast of the country and Brahmani river basin, a water rich basin on the east coast. A simplified but broad based model called Basin-wide Holistic Integrated Water Assessment (BHIWA) model was developed keeping in mind the specific objectives of the CPSP and applied to each of these two selected river basins. The results of the preliminary assessment for these two basins were first deliberated at the ‘basin level consultations’ in January

2003. Subsequently, the chosen model was amplified/fine tuned and more detailed assessments carried out. Outcomes of these assessments including their approximate extrapolation and policy related issues emerging from the studies were presented in a National Consultation held in

November 2003. Subsequently, two more river basins of India – Tapi river basin on the west coast and Pennar river basin on the east coast were selected for similar detailed assessments. A location map of the two selected river basins is shown in Figure 1.



Figure 1. Location Map of the two selected River Basins in India

1.0.2 Purpose and scope of the report

This report is prepared to typify and highlight the problems of a water deficient basin and determine relevance and efficacy of the plausible policy options to support the regional and countrywide water issues. The report is based primarily on use of the BHIWA model, which is calibrated approximately based on 5-year period (1995-2000) data. The past (1960) situation is studied essentially to set pre-development situation, to understand surface and ground water availability and more specifically to determine the pattern of dry season (Oct.-May) river flows, Alternative scenarios of future (year 2025) are analysed under an integrated and sustainable use of resources for all the three sectors. A brief description of model is given in Annexure 1 to help the reader in understanding the capabilities and broad working of the BHIWA model written in Microsoft EXCEL. It must be mentioned that model as developed and used here is essentially a basin/sub-basin level tool for assessment in broad hydrologic domain capable of quantifying and considering human impacts through storage, withdrawals, returns, consumptive and non-consumptive water uses, on the resources. It is not a *planning tool* for within basin/sub-basin project planning.

1.0.3 Structure of the Report

Chapter 1 provides the background to CPSP and modelling approach used to provide detailed water assessments as a first step to explore policy options based on a comprehensive analysis of selected sample basins. It covers the general description of the basin based on secondary data collected through different sources to highlight the water and water use related issues, including State Plans of future water development. In Chapter 2 is given in detail the application of BHIWA model for assessing past, present and future conditions of the resource. The “present” condition has been studied twice – once in the calibration mode, for understanding the unsustainable ground situation, and later, in the simulation mode after making the situation sustainable through further anthropogenic changes to make the situation sustainable. Both calibration and simulation applications are covered giving salient information and aggregated results for a comparative study. Chapter 3 covers the basin specific findings and their extension to overall issues as well as other similar basins. The latter is based on abstracting main results in the form of key water situation (state of resource and its use) indicators. The report needs to be studied along with a soft copy of the BHIWA model as applied to Sabarmati basin, to assist the water professionals to

understand the finer and sub-basin level details.

1.1 Sabarmati River Basin

Sabarmati river basin is one of the 24 river basins of India. This water deficit basin lies on the west coast of India between latitudes 22° N to 25° N and longitudes 71° E to 73° 30' E and is spread across the States of Gujarat and Rajasthan. Sabarmati river originates at an altitude of 782 m in the Aravalli Hills in Udaipur, in the state of Rajasthan and flows for a length of 371 km in southwest direction, of which 48 km lies in Rajasthan and 323 km in Gujarat. The map of the Sabarmati river basin is shown in Figure 2.

The river is bounded on the north and northeast by Aravalli Hills, on the east by ridge separating it from Mahi basin, on the south by the Gulf of Cambay and on the west by the ridge separating it from the basins of minor streams draining into Rann of Kachch and Gulf of Cambay. The basin is triangular in shape with the main river as the base and the source of the Watrak river as the apex point.

The river outfalls in the Gulf of Cambay in the Arabian Sea. The basin has total drainage area of 21,565 km² of which 17,441 km² is in Gujarat and 4,124 km² is in Rajasthan. This basin area does not include minor catchment of the tributary Bhogavo which meets the Sabarmati estuary and the development of which is not likely to be integrated with the development of the main river basin. The Sabarmati river basin extends over parts of Udaipur, Sirohi, Pali and Dungarpur districts of Rajasthan, and Sabarkantha, Kheda, Ahmedabad, Mehsana, Gandhinagar, and Banaskantha districts of Gujarat state.

The basin has been studied in much greater details by the Narmada and Water Resources Department of the Government of Gujarat, having the major stake in Sabarmati waters. Gujarat state as a whole has an annual per capita water availability of 1137 m³, which is only about 474 m³ in North Gujarat (GOG, 2000). This general scarcity is compounded by huge variations in rainfall from year to year. The Sabarmati basin, which lies mainly in the region, has even larger variations. The Government of Gujarat in its hydrology studies, normally divides Sabarmati basin in three parts as follows:

Dharoi sub basin – This covers drainage area of the main river up to Dharoi dam. Catchment area of the sub basin is 5,540 km², out of which about 2,640 km² lies in Gujarat state.

Hathmati river sub basin – It covers drainage area of

Watrak sub basin – This covers the remaining drainage area of the main river downstream of the confluence of Khari and up to its meeting with the Gulf of Cambay. Catchment area of the sub- basin is 10,478 km², out of which as much as 9,337 km² is lying in Gujarat state.

The Sabarmati river has 5 tributaries of which two tributaries, namely Wakal and Sai originate in Rajasthan. Wakal joins the river on the left bank near village Ghanpankhri. The Sai River joins the main river near Mhauri villages. Pamri, Manas, Kusumbhi rivers are the sub-tributaries of river Wakal. The remaining three tributaries namely, Harnav, Hathmati and Watrak originate in Gujarat. Harnav joins the left bank of Main River at



about 103 km. Hathmati joins the river on the left bank at about 170 km from its source. Ghuvai and Boroli rivers are the sub-tributaries of Hathmati river. Watrak joins the left bank of the river about 65 km downstream of the Ahmedabad. Khari, Meshwa, Majhum, Warasi, Mohar and Shedhi are tributaries of Watrak. Few kilometres before the mouth, the river Sabarmati is joined by river Bhogavo, which originates in Saurashtra, on the West of Gulf of Cambay. The drainage area of this tributary is not considered. The drainage areas and length of five tributaries of Sabarmati river are shown in Table 1.

Table 1.
Drainage Area and Length of Tributaries of Sabarmati River

Tributary	Location	Area (km ²)	Length (km)
Wakal	Left Bank	1625	88
Sai	Right Bank	946	95
Harnav	Left Bank	972	75
Hathmati	Left Bank	1523	105
Watrak	Left Bank	8638	248

1.3 Climate and Rainfall

Sabarmati river basin has a tropical monsoon climate with three seasons, the monsoon (kharif, between late June to October), the cooler rabi (November to February) which is dry except occasional rain in November and in the coastal region, and the hot summer season (March to mid June). The average annual temperature ranges between 25°C to 27.5° C. The rainfall occurs almost entirely in monsoon months (June to September) with an average annual rainfall of the basin as about 750 mm with significant regional variations. The co-efficient of variation of annual rainfall over the basin is rather high and ranges between 42-65%. The rate of evaporation is highest during April to June due to sharp rise in temperature and increase in wind speed. The average annual evapo-transpiration (ETo) in the basin ranges between 1500 mm - 2000 mm.

1.4 Geology

Rocks belonging to pre-cambrian period in its northern and eastern parts whereas the recent alluvial deposits underlain by rocks of pre-cambrian age occupy its western and southern parts.

Alluvial deposits underlain by pre-cambrian rocks occupy the Western and Southern parts of the basin. Major portion of the Southern and Central parts of the basin is

occupied by recent alluvium. Thus, almost lower 2/3 part of Sabarmati basin is covered by alluvium. These alluvial deposits consist of sand and clay. The sandy layers of these alluvial deposits have good porosity and permeability and form good aquifers. The maximum thickness of the deposits here is about 2,600 m. Cretaceo-Eocene eruptions of lava form basalt in a scattered pattern in the Southern part of the basin. (INREMF, 2001 and GOG, 1996)

1.5 Physiography and Soils

Physiographically, the Sabarmati basin can be divided into three broad physiographic units.

- Rock outcrops moderately sloping to gently sloping, undulating dissected hills and ridges having narrow pediments sharp hills and hill slopes. This unit lies in the northern border of Sabarmati basin. The Sabarkantha high lands are formed by outliers of the Aravalli hills and covers the north-eastern part of Sabarmati basin.
- Gently sloping pediments to gently sloping alluvial plains. This unit is located between Khedbrahma to Ahmedabad. The basin is drained by rivers and tributaries such as Watrak, Mazam, Meshwo, Hathmati etc.
- Level to nearly levelled, alluvial plains. This unit is located between Ahmedabad and Gulf of Cambay and falls under flood plains of Limdi-Bhogavo and Sabarmati.

The soils of the physiographic unit (A) are shallow, somewhat excessively drained, loamy skeletal, occurring on moderately undulating hills and ridges with severe erosion and severe stoniness. Taxonomically the soils have been classified into lithic ustochrepts.

1.6 Land Use

The Revenue Department of Gujarat State Government classifies the land into three major categories as follows:

- Land under Forest*,
- Land not available for cultivation* – this include barren, hilly, marshy, saline, land under buildings, roads, railways and other uses and hence not available for cultivation on an almost permanent basis,
- Cultivable land* – this include pastures, culturable wastelands or fallow lands and land under actual cultivation, both irrigated and rainfed.

The basin is not very rich in forests but considerable

forests exist in the upper area. Presently, the total forest area is estimated at 1,855 km² in Gujarat and 1,987 km² in Rajasthan. As per the old Gazetteer, the forest are classified as mixed dry deciduous type with varying densities. The tree species include teak, kaladhov (*Degogissio pandla*), Khakaro (*Butea monorperma*) and Limdo (*Azadirachta Indica*). Mahuda is also common with undergrowth of Jai Parvathi (*Myctan thesarbortristis*).

Area under permanent pastures and miscellaneous tree crops is currently estimated at 775 km² in Gujarat and 127 km² in Rajasthan. Land use pattern of the basin as used in the studies, after slight statistical adjustments, is shown in Table 2.

Table 2.
Land Use Pattern of Sabarmati Basin (km²)

Description	Area
Geographical area	21,565
Forest area	4,097
Land under pastures	996
Land not under cultivation	4,135
Net area sown	12,237
Gross area sown	15,196
Area sown more than once	2,959

The land use data has been roughly verified from IRS-ID LISS III satellite imageries. The current land use is depicted on map shown in Figure 3.

Agriculture is the dominant land use in the basin. Agriculture is both rain fed and irrigated in somewhat equal measure. Cropping intensity varies greatly among basin districts. Besides the field crops such as wheat, paddy, jowar (sorghum), maize, cotton, tobacco, pulses, oil seeds and groundnut (peanut), in some areas, particularly near urban settlements, fodder crops and vegetables are commonly grown. Fruits orchards and banana plantations are also found in some parts, especially the Kheda district.

The Kharif (monsoon period) is the main cultivation season. The predominant crops grown in the Kharif season are bajra (pearl millet), cotton, groundnut, jowar, rice and maize. Most of the pulses, millets and tobacco are the other kharif crops and occupy relatively small areas. Rabi season (winter) generally commences in October, and the principal rabi crop is wheat. Other rabi crops are rapeseed,

mustard, cumin and isabgol. Cultivation of summer crops depends entirely on availability of irrigation water and bajra is the main summer crop. The main fruit crops grown are mango, banana, citrus, guava, papaya, chiku, (sapota), ber, date palm, and coconut.

The cropping pattern in the basin for the year 1995-96 for food crops and non-food crops is shown in Table 3. Although the cropping pattern is generally stable, there may be slight variation in the areas grown under each crop in different years.

Table 3.
Cropping Pattern in Sabarmati Basin (1995-96)

A. Food crops	Percentage of gross cropped area, under the crop
Paddy	15.8
Wheat	13.1
Bajra	15.1
Maize	9.2
Other cereal	0.0
Total cereal	53.2
Groundnut	2.2
Mustard	2.9
Total edible oilseeds	6.8
Total pulses	9.6
Total condiments and spices	1.5
Total fruits	1.2
Total vegetables	2.2
Sugarcane	0.1
Total food crops	74.6
B. Non food crops	
Cotton	6.5
Castor	7.3
Tobacco	4.4
Total fodder crops	7.2
Total Non-food crops	25.4
C. Total food & Non-food crops	100

1.7 Water Resources

There are a number of river Gauge and Discharge (G&D) sites maintained both by Central Water Commission (CWC)¹ and the Water Resources Department of the

¹ The Central Water Commission (CWC) is a premier Technical Organisation of India in the field of water resources and is charged with the general responsibilities of initiating coordinating and furthering in consultation with the State Governments concerned, schemes for control, conservation and utilisation of water resources throughout the country, for purpose of flood control, irrigation, navigation, drinking water supply and hydro power development. The Commission inter alia, is involved in collection, collation and publishing of hydrological, hydro-meteorological, sediment and water quality data. The gauge, discharge and sediment sites indicated in Sabarmati river basin, inter alia, form part of the CWC's overall network.

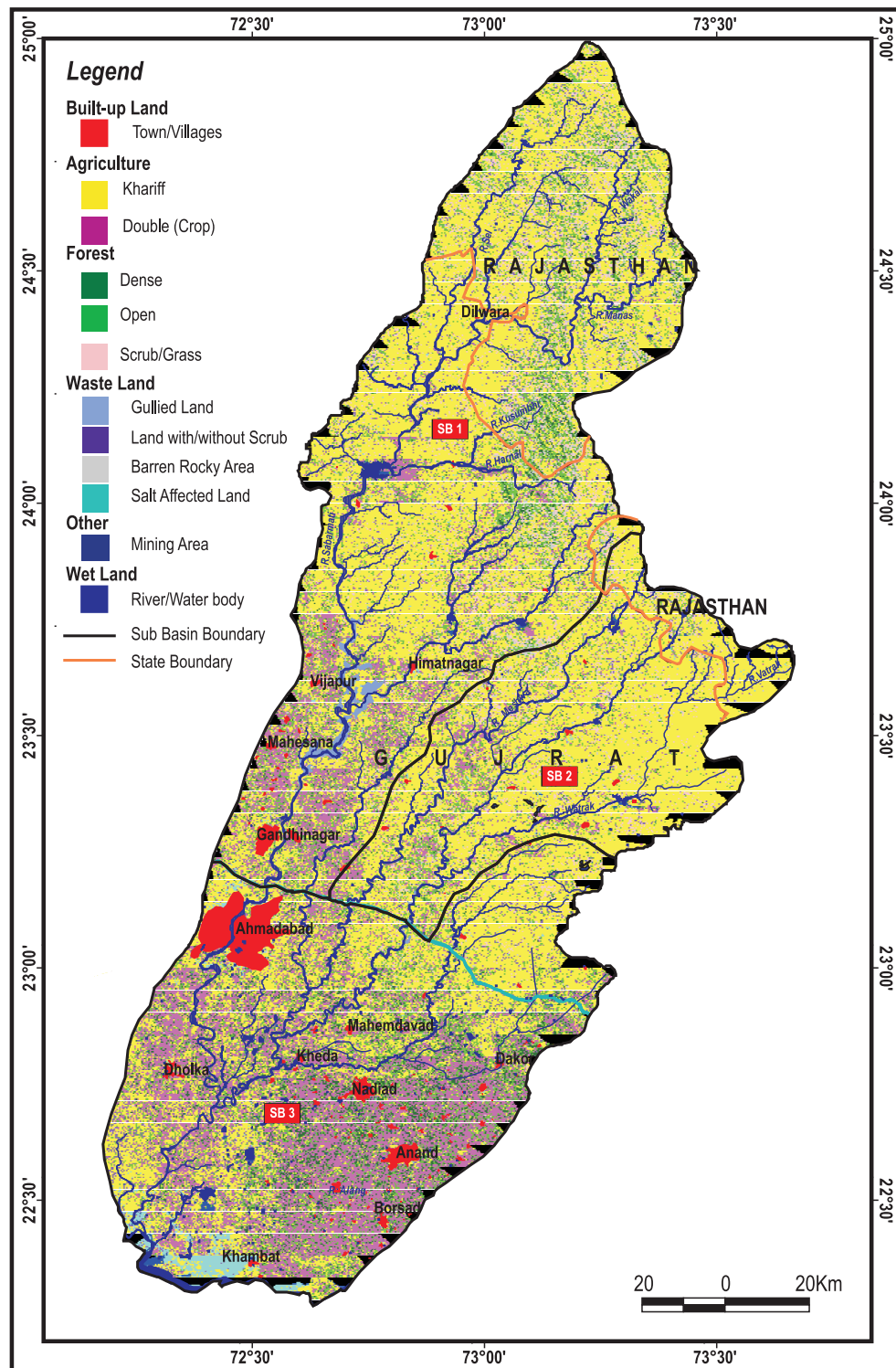


Figure 3. Land Use Map of Sabarmati River Basin

Gujarat state. The locations of the key G&D sites are shown on the Sabarmati river basin map (Figure 2).

The annual surface water resources have been estimated sub- basin wise by Department of Water Resources, Government of Gujarat, based on available monthly time series of stream flow and rainfall (GOG, 1996). Their estimate of the average annual surface water resource for the Gujarat portion of the basin is 3,256 million cubic meters with sub basin wise break-up as shown in Table 4.

Table 4.
Sub Basin Wise Mean Annual Surface Water Resources
(10⁶ m³) (Gujarat Portion only)

Sub- basin	Water resources
Dharoi	629
Hathmati	672
Watrak	1955
Total:	3256

The total mean annual surface water resources of the drainage area of the Sabarmati river falling in the Rajasthan portion have been estimated as 513 million cubic meter by Department of Irrigation, Govt. of Rajasthan. Thus the total mean annual surface water resources of the basin are estimated as 3769 million cubic meters.

The CWC estimates renewable annual water resources of the Sabarmati river basin as 3810 million cubic meters

per year (CWC,1993). This includes surface and ground water resources. The potentially utilisable surface water resource in the basin as estimated by CWC amounts to 1930 million cubic meters (CWC,1988).

Average annual renewable groundwater recharge in the Gujarat portion of the Sabarmati river basin including its availability for different uses as estimated by the Water Resources Department, Govt. of Gujarat is given in the Table 5.

The average recharge of the groundwater for the Rajasthan portion of the Sabarmati river basin as estimated by Department of Irrigation, Govt. of Rajasthan is 133 million cubic meter per year, out of which 38 million cubic meter per year is being utilised at present.

The total utilisable groundwater recharge in the basin amounts to about 1800 million cubic meter/year based on district wise groundwater potential estimates of the Central Ground Water Board² (CGWB, 1995). As per the estimates, around 15% of the available potential is proposed as reserved for domestic water needs etc. and balance is indicated to be available for irrigation use.

Typical maps showing water level contours (reduced levels) of confined and unconfined aquifers for May and October 2002 obtained from Gujarat Water Resources Development Corporation Limited, Gandhinagar are presented as Annexure 2.

Table 5.
Sub Basin Wise Average Annual Groundwater Resource (10⁶ m³)
(Gujarat Portion only)

Sub Basin	Replenishable groundwater recharge (GR) industrial use	Groundwater recharge for domestic and industrial (5% of GR)	Groundwater recharge for environment (15% of GR)	Groundwater recharge for agricultural use (80% of GR)
Dharoi	224.65	33.70	11.23	179.72
Hathmati	908.31	136.25	45.41	726.65
Watrak	1437.41	215.61	71.87	1149.93
Total	2570.37	385.56	128.51	2056.30

² Central Ground Water Board (CGWB) is the Central Organisation of Government of India entrusted with the responsibilities of hydro-geological surveys, exploration, assessment, development and management of groundwater resources in the country. The Board inter alia, carries out periodic assessment of groundwater resources, publication of maps and reports, water balance studies, artificial recharge studies and reviews regulation of groundwater development and rainwater harvesting schemes.

1.8 Water Export

Present (1995)

The currently planned exports (1995) from Sabarmati river basin are about 260 million cubic meters.

Future

The total export from Sabarmati river basin as projected by Govt. of Gujarat for the year 2025 is 1417 million cubic meters, of which 119 million cubic meters will be for Rajasthan State to meet the domestic requirement and 1290 million cubic meters will be for areas in Gujarat outside of the Sabarmati river basin. Of this 1290 million cubic meter, about 65 million cubic meters are for domestic needs and remaining 1233 million cubic meter are for irrigation purposes. In the current studies, lesser values of exports have been used for some scenarios.

1.9 Water Import

Present (1995)

Water is currently being imported from the Mahi river basin to the portion of Sabarmati river basin in Gujarat to the extent of 1584 million cubic meters, of which 128 million cubic meters is to meet the domestic needs, and remaining 2030 million cubic meters is for irrigation.

Future

As per the plan of Govt. of Gujarat, the total imports (including existing and future) for different uses, from Mahi and Narmada river basins will be as follows:

Table 6.
Proposed Import of Water from Mahi and Narmada River Basins (10^6 m^3)

Sector	Mahi river	Narmada river	Total
Irrigation	2,030	1,943	3,973
Domestic	128	195	323
Total	2,158	2,138	4,296

However, in the CPSP studies, somewhat small level of import is studied. For the Gujarat plan the Future 2025 import is kept at 3938 million cubic meters. For other scenario it is kept around 3084 million cubic meters.

1.10 Water Resources Development

The Sabarmati basin is one of the most intensively irrigated regions in Gujarat. Irrigation continues to be a major user of water in the basin in spite of the fact that most part of the basin falls in water stressed region of the

state. As of 1995, there are 11 major and medium surface water storage projects and 5 diversion projects and a number of minor projects in the Gujarat portion of the Sabarmati river basin (Figure 4). Project wise details of these projects are given in the Annexure 3. The total area irrigated in Gujarat portion of Sabarmati basin from the major and medium projects is 1,98,173 ha. (see Annexure 3)

There are eight numbers of ongoing and proposed medium and minor projects, namely; (i) Chandrana (ii) Khedva (iii) Kadiyadra (iv) Pal (v) Rolla (vi) Lank (vii) Varanasi and (viii) Mahadevpura to irrigate a total area of 11,961 ha in the basin. The Water Resource Department, Government of Gujarat proposed to bring additional 2,68,366 ha under irrigation by extending Dharoi Command (32,487 ha), Fatewadi Command (62,930 ha) and Narmada Command (172,949).

There are 42 minor projects in the Rajasthan portion of the basin providing irrigation to an area of 8,755 ha. 18 minor projects are under construction and will irrigate additional area of 10,000 ha. A further 26 minor irrigation projects are proposed by the Irrigation Department of Government of Rajasthan for providing irrigation benefits to an area of 17,000 ha. Thus, on full development all the 86 minor irrigation projects, the irrigation potential would be 35,755 ha.

In the CPSP studies, the present Gross Irrigated Area (GIA) of 789,500 ha is assumed to increase to 1,243,500 ha in the BAU (2025) scenario. In the Gujarat plan it goes up to 1,235,400 ha. In other scenarios, it is varied between 1,032,500 ha to 1,222,000 ha.

1.11 Population

The total human population in the Gujarat portion of the Sabarmati river basin was 11.44 million (2001), of which, 5.99 million was urban and 5.45 million was rural, the total population of the Rajasthan portion of the basin in 2001 was 0.31 million and the entire population was rural. Thus, the total population of the basin as a whole was 11.75 million comprising 5.99 million as urban and 5.76 as rural.

The projected population of the Gujarat part of the basin in the year 2025 is 19.47 million, of which 10.81 million will be urban and 8.66 million will be rural. The projected population of the Rajasthan portion of the basin in 2025 will be 0.39 million and the entire population will be rural. Thus the total projected population of the basin will be 19.86 million, of which 10.81 will be urban

Table 7.
Decade-wise Human Population in Sabarmati Basin (10⁶)

Year	Rajasthan Portion			Gujarat Portion			Total basin		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
1971	0.14	-	0.14	3.34	2.62	5.96	3.48	2.62	6.10
1981	0.18	-	0.18	4.29	3.39	7.68	4.47	3.39	7.86
1991	0.25	-	0.25	4.82	4.46	9.28	5.07	4.46	9.53
2001	0.31	-	0.31	5.45	5.99	11.44	5.76	5.99	11.75
2025*	0.39	-	0.39	8.66	10.81	19.47	9.05	10.81	19.86

* Projected

and 9.05 million will be rural. The decade wise population (urban and rural) for the past 30 years and the projected population for the year 2025 are given in Table 7.

The per capita water availability in 2001 in the basin was 324 cubic meter/year per capita, which is the lowest in India and much below the Falken Mark's scarcity mark of 1000 cubic meter per capita per year. The water availability will reduce to 192 cubic meter/capita/year as per the projected population in 2025.

1.12 Present Water Use (1995) and Future (2025) Requirement

Agricultural water use for irrigation

Sabarmati basin is one of the most intensively irrigated regions in Gujarat and agriculture will continue to be major user of water in the basin. The area under irrigation has shown dramatic increase over the years due to the construction of storage and diversion structures on the river and its tributaries and easy access to groundwater abstraction because of wide scale use of electric pumps and easy availability of institutional financing. Source wise area irrigated within the basin is shown in Table 8.

The current surface water withdrawal for irrigation in the basin has been estimated as 1,304 million cubic meters per year. The groundwater withdrawals for irrigation is estimated as 4,449 million cubic meters. The total demand for the year 2001 was of the order of 5,750 million cubic meters.

The irrigation water withdrawal demands from surface water considering the future (2025) expansion of areas and development of commands work out up to 1,726 million cubic meters. The groundwater withdrawal for

Table 8.
Source-wise Area Irrigated within the Sabarmati Basin

Source	Area (ha.)
Surface water	
Major, Medium and Minor projects	212,301
Mahi Right Bank Canal	212,295
Total Surface water	424,596
Ground water	
Public tube wells	53,093
Private tube wells	280,486
Dug wells	386,705
Total ground water	720,284

irrigation would also go up, and this has been estimated to vary widely amongst the scenarios developed in CPSP. There could be as high as 7,585 million cubic meters in the Business as Usual scenario, but considering the need for reducing this, with changes in management strategies etc, for some future scenarios, reduced withdrawal of up to 2,794 million cubic meter are also considered. The total irrigation demand, in terms of withdrawals, in the Gujarat plan, works out to 6,833 million cubic meters (Patel, et al 2002). However, the corresponding figure in the CPSP studies is 8,259 million cubic meters.

Domestic use

In the CPSP studies, the drinking water requirements for urban, rural and live stock population, for the present, are worked out as 349 million cubic meters. Domestic requirement in the year 2025 for urban, rural and live stock population is worked out for the corresponding to projected population in the year 2025 works out to 1,257 million cubic meters.

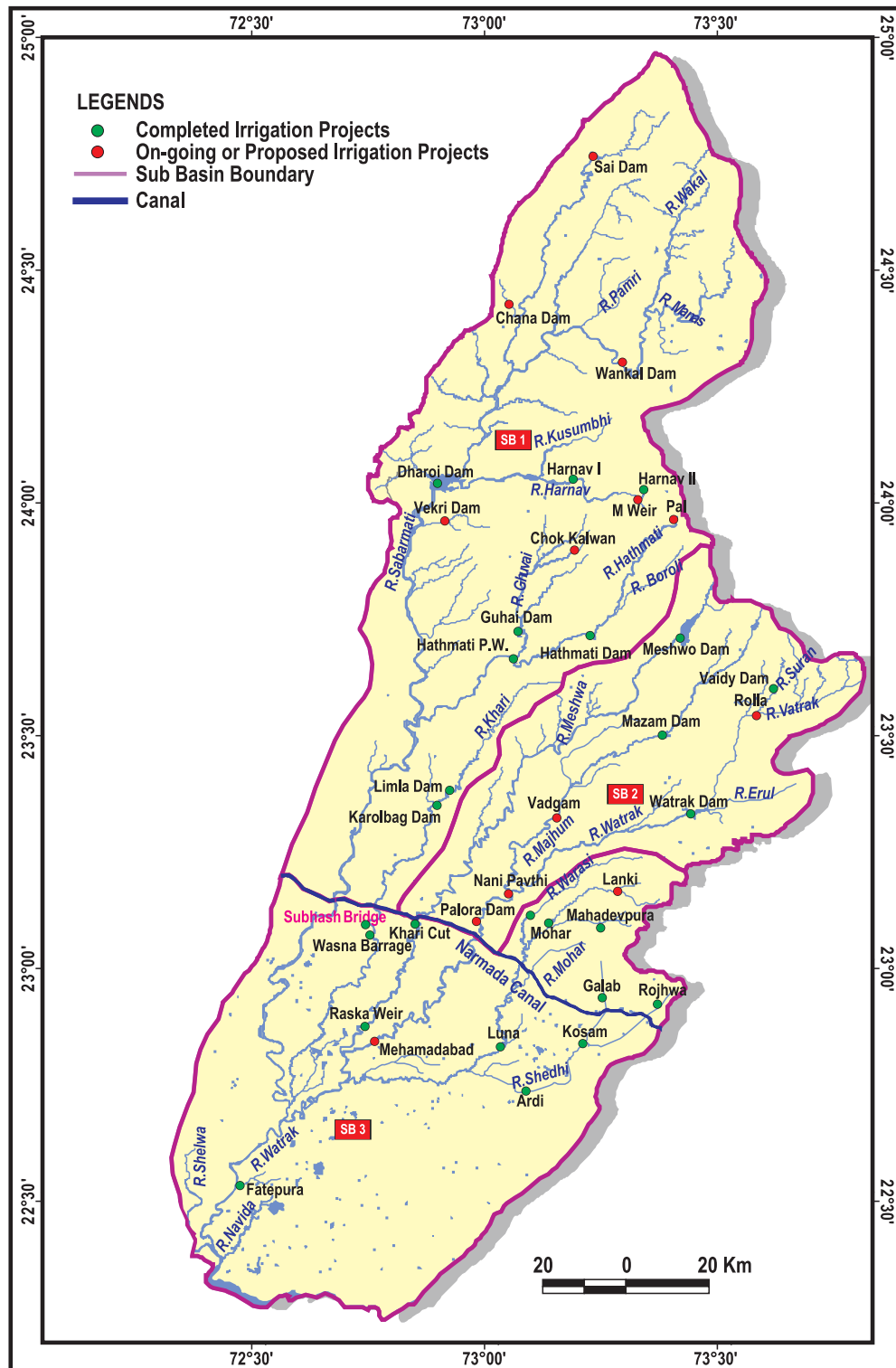


Figure 4. Map of Sabarmati River Basin Showing Irrigation Projects

Industrial use

There are 20 industrial estates developed by Gujarat Industrial Development Corporation (GIDC) in Sabarmati basin. At present there are about 3365 industrial units in three industrial areas near Ahmedabad. Majority of them are textile industries. The next most common industry is chemical industry. Other important industries in the basin are cement, ceramics, petroleum, dairy products, sugar, edible oil, pharmaceutical, electronics and engineering etc. The present demand for industrial water, in the 20 industrial estates is 99.64 million cubic meters. The break-up of this demand is shown in Annexure 4. The total industrial water demand at present, as used in the studies, amounts to 110 million cubic meters per annum. The demand is projected to be 470 million cubic meters per annum by the year 2025.

Total water use in terms of withdrawals, as resulting from the present studies, for different sectors for present and future conditions for the basin is given in Table 26 and its abstract is in the Table 9.

1.13 Water Resources Management Issues Emerged from Basin Level Consultations

In order to identify the specific water development and management issues, basin level consultations for the Sabarmati were held at Ahmedabad on 23-24 January 2003 based on preliminary water assessments. Key presentations were made on integrated water resources development and

management, rain-fed agriculture, treatment and reuse of municipal and industrial wastewater, and water needs of forestry and mangroves, besides presentation of past, present and future state of water availability, based on preliminary analysis and formulation of alternative scenarios of the future. More than 55 professionals, non-governmental organisations (NGOs), representatives of Consultancy and Contributing Organisations participated in the consultations. The comments/suggestions received from the participants were used by the CPSP study team for formulation of an integrated model to evaluate policy options in the context of integrated and sustainable development. The initial consultations also helped to avail and compile the existing Knowledge Base (KB).

Some of the main water related issues of Sabarmati basin identified through these preliminary consultations are as follows:

1.13.1 Water Scarcity

Sabarmati river basin falls in semi-arid zone. Rainfall in the basin is low and highly erratic. Rainfall occurs in only four months in a year. The per capita annual water availability is one of the lowest among the Indian river basins and the present use is sustained by large import of water from adjacent river basins. Possibilities of sustaining the present over use of groundwater through artificial recharge and inter-basin transfer of additional surface water to meet future needs may require to be explored.

Table 9
Water Use (Withdrawals) for the Present and Future Conditions (10^6 m^3)

Item	Past	Present	Future I B as U with Narmada import	Future II B as U without Narmada import, and other future scenarios
Surface water withdrawal for irrigation in basin	183	1304	1726	694 to 1477
Surface water withdrawal for exports, for irrigation, outside basin	0	260	425	260 to 1417
Total surface withdrawal for irrigation including exports	183	1564	2151	1468 to 2531
Total surface withdrawal, including exports and D&I	207	1673	3118	2267 to 3291
Total groundwater withdrawal for irrigation including pumping to canals	522	4499	7585	2794 to 7836
Total groundwater withdrawal, for irrigation, pumping and D&I	662	4849	8345	3551 to 8596

1.13.2 Pace of Urbanisation and Increase in Urban Water Use

Rapid urbanisation is taking place in the basin. About 52% of the population is urban. Nearly 50% of the basin population is concentrated in Ahmedabad and Gandhinagar districts and more than three-fourth of the urban population is residing in the cities of Ahmedabad and Gandhinagar. There is a huge demand for public water supply in these cities, which is bound to increase substantially in future due to demographic trends and rapid growth of urbanisation and income levels. Consequently the amount of wastewater generated and need for much greater treatment facilities and disposal of the treated effluents will be required. It was suggested that the policies to use the treated effluents for irrigation without allowing these flow back to rivers may be explored. Such measures are coupled with augmentation of water supply requirement by imported surface water. At present partially treated effluents are already being utilised for irrigation in the Sabarmati basin, but mixing with river waters is also occurring.

1.13.3 Increasing Industrial Water Requirements

There are 20 industrial estates operating in the Sabarmati river basin. The industries in the basin include small-scale industries, factories, medium and large industries. There are 2,687 medium and large industries. In addition, there are 45,133 small-scale industries. They include textiles, paper products and printing, leather products, rubber and plastic industries, chemical and chemical products, and are highly water consuming (INREMF, 2001). The region

being conducive to cotton growing, number of textile and dyeing industries has come up in the basin particularly in the Ahmedabad district. Dairy farming, processing of milk and its products is an important industry in the region. In addition, industries dealing with chemical, starch, drugs and pharmaceuticals, glass and ceramics, cement etc. have come up in the basin in a big way. The demand of water for industries is expected to grow much more as a result of rapid growth of industries owing to high pace of economic growth. This will call for much greater efforts to manage industrial demands to avoid likely conflicts with water availability for other uses.

1.13.4 Over Exploitation of Groundwater

There is a severe shortfall in the availability of surface water in the Sabarmati river basin, especially in upper sub-basin. Perhaps, in view of the easier accessibility and timeliness, and in the absence of any regulation, the ground water use has increased markedly. This has led to its over exploitation in about 23 out of 29 talukas³. (Patel, et al 2002).

1.13.5 Water Pollution

Due to discharge of domestic wastewater and industrial effluents, partially treated/untreated into the tributaries of the river and main Sabarmati river, surface water pollution is rather high. There is deterioration of in the quality of groundwater, due to large returns from irrigation and dumping of industrial effluents on lands. There is a need for a close monitoring of surface and groundwater quality besides adopting policies for preventing overuse of groundwater.

³ Taluka is an administrative unit within a district.

CHAPTER 2

APPLICATION OF BHIWA MODEL

2.0 Modelling Framework

A holistic and integrated water assessment model called 'BHIWA' was especially developed to provide an integrated computational framework for a basin/sub-basin level assessment of water resources with a view to evaluate water sector policies, keeping CPSP goals in mind. The model considers the entire land phase of the hydrologic cycles and is capable of depicting human impacts such as changes in land and water use, as also impacts of water storage and depletion through withdrawals for various water uses and addition through returns/ inter-basin water transfers. The basic objectives of the model are:

- To consider the impact of changing land and water use on the resources, taking into account interdependencies between different elements of the land phase of the hydrological cycle
- To quantify and integrate sectoral water uses, and
- To formulate and analyse scenarios to evaluate various policy options for development and management of water and related land resources.

The model can be used effectively for the following purposes:

- a) Understanding resources and sectoral needs in an integrated manner considering sustainability of water for human use as well as environment, and
- b) Creating and improving knowledge base for meaningful and transparent dialogue.

The model is especially useful for assessing future water needs under different scenarios of development and management, and for analysing impact of different policy options on the state of water availability for an integrated and sustainable use of the resource.

The model was calibrated based on data for present conditions and applied to identify main issues and challenges in basin water management and explore policy options through the analysis of alternate scenarios of the future (year 2025). The model uses water balance approach and prepares separate water balances for surface and groundwater systems as well as an overall water balance for the basin/sub-basin.

The model can be calibrated making use of data for the past or present conditions for the given basin. Once the model is calibrated, the user can proceed to simulate and analyse alternate scenarios of future development and management of resources. Scenarios can be developed in the model in terms of changes in land use, crop areas under rain-fed and/or irrigated agriculture, cropping patterns, irrigation efficiencies, imports and exports of water, surface (reservoirs) storage, proportion of surface and groundwater withdrawals, etc.

By simulating past conditions of limited water use in the basin, the model can also help the user in setting up *minimum reference flows* for maintenance and enhancement of river ecology and environment. Comparison of such flows with projected future status of balance river flows can help in setting limits on surface and ground water withdrawals, including extent of lowering of groundwater tables to meet prescribed "environment flow" requirements. Figure 5 gives a schematic representation of the model. The salient features of the model, including its various computational modules, input and output data are outlined in Annexure 1.

2.1 Application of BHIWA Model to Sabarmati River Basin

The model was calibrated for the present (1995) conditions using short term rainfall and runoff records for the period 1995-96 to 1999-2000 and applied to derive

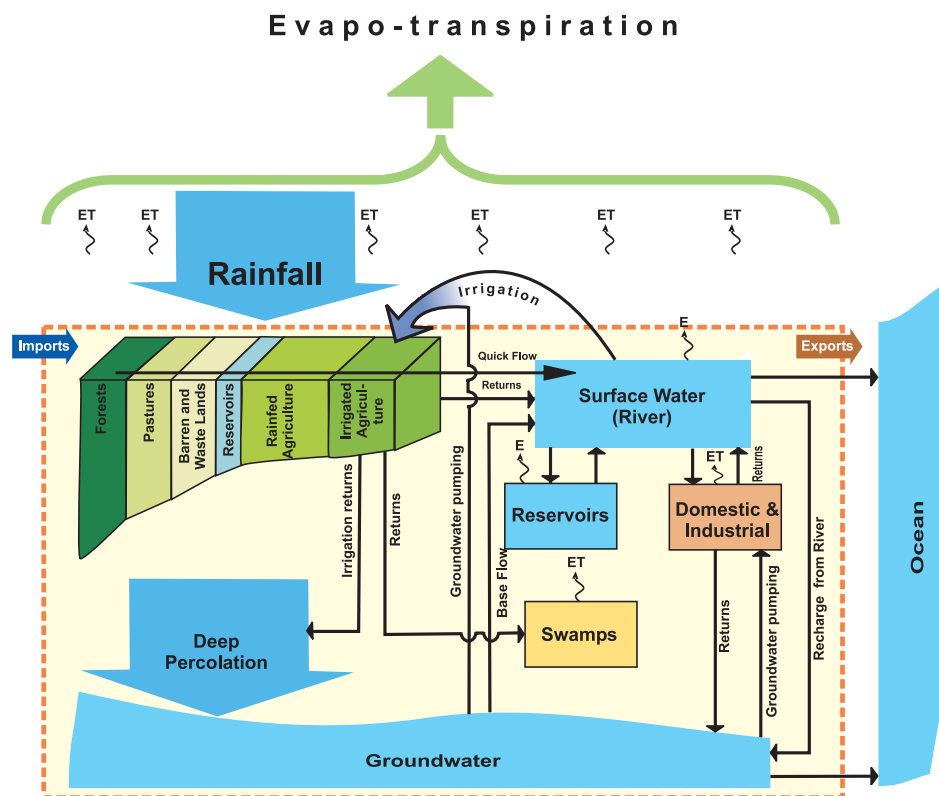


Figure 5. Schematic Diagram of BHIWA Model

responses corresponding to past and future scenarios using monthly time steps. Studies are done at the sub-basin level. The basin was divided to allow grouping of areas having similar hydrologic and water use attributes. For modelling applications the basin has been divided into three sub-basins as follows:

- Sub-basin 1 (SB1) : Catchment of main stem of Sabarmati river basin up to Narmada canal crossing (10,050 km²)
- Sub-basin 2 (SB2) : Catchment of Watrak tributary up to Narmada canal crossing (4,363 km²)
- Sub-basin 3 (SB3) : Downstream catchment of the basin (7,152 km²)

The sub-basins are shown on the Sabarmati river basin map in Figure 2. For the purpose of these studies, the catchment area of the Bhogavo tributary which joins the Sabarmati river in the estuary is not considered in the SB3 area, as the hydrological as well as water use conditions of Bhogavo catchment differ substantially from the rest of the sub-basin and can certainly form a different entity. As the

Bhogavo tributary joins the Sabarmati river at the fag end, excluding the flows of Bhogavo river does not impact the analysis and the results of the Sabarmati basin.

Most of the surface storages are concentrated in SB1. While SB2 has some surface storage, SB3 has no storage but has areas irrigated through import of Mahi river waters and groundwater.

2.2 Data Used in Model Calibration

Secondary data are available on hydrological and other aspects including irrigation infrastructure, soils, rain-fed and irrigated agriculture from surface and ground water resources. The soil moisture capacity has been varied for each type of soil and land use, and values consistent with the likely root zone depths and field capacities were used.

The average observed flows for the hydrological years 1995-96 to 1999-2000 at Gandhinagar on Sabarmati (7,843 km²), at Dabha on Watrak (1,587 km²), at Mehamabad on Watrak (3,237 km²), at Bilodra on Shedi (2,124 km²), at Ambadiyara on Mazam (1,094 km²) and at Minamuda on Meshwa (1,360 km²) were utilized in the

Table 10
Observed Flows at Different Gauge & Discharge (G&D) Sites (10^6 m^3)

Year	Sabarmati at Gandhinagar (7843 km ²)	Watrak at Dabha (1587 km ²)	Mazam at Ambadiyara (1094 km ²)	Meshwa at Minamuda (1360 km ²)	Shedi at Bhilodra (2124 km ²)	Watrak at Mehamadabad (3237 km ²)
1995-96	29.97	21.30	53.93	57.13	62.98	15.97
1996-97	110.63	92.58	51.45	39.24	385.11	34.43
1997-98	1029.4	1010.12	502.69	208.46	1210.26	636.97
1998-99	269.6	262.32	174.26	161.13	266.08	83.42
1999-2000	16.13	15.52	21.27	16.28	87.97	57.96

model calibration. Table 10 shows the observed flows at relevant Gauge & Discharge (G&D) sites. The flows at the outlets of SB1, SB2, and SB3 were estimated from the observed flows at these site(s), in the respective sub basin in proportion to drainage area and are furnished in Table 11.

The monthly rainfall data for the three sub-basin used in calibration for the years 1995-96 to 1999-2000, along with monthly long term averages used in simulation are given in Annexure 5 and the corresponding figures for “typical good, average and bad monthly rainfall (sub basin wise) are listed in Annexure 6. The monthly reference evapo-transpiration (ET_o) data as used in the studies are given in Annexure 7.

2.3 Land Use, Crop and Irrigation Statistics

The available *Taluka* (sub-district) statistics of land use, crops and crop areas and irrigated areas from surface and groundwater sources were compiled sub-basin wise. Agriculture land use - both rain-fed and irrigated was further subdivided using trial and error reflecting seasonal cropping cycles. In all, each sub basin was classified into 20 standard land use parcels, These included land parcels under forest and miscellaneous trees (P1), Permanent pastures (P2), land not available for cultivation - waste

and fallow lands (P3), land under reservoirs (P4) and a number of parcels for land under rain-fed and irrigated agriculture use. As mentioned before, the latter were sub divided into parcels to represent broadly seasonal cropping pattern cycles such as perennial crops, two seasonal with a single crop and not cropped in third season, lands that are under two separate crops in two seasons and fallow in one season, lands that are cropped only in one season and remain fallow in other two seasons etc. Similarly, while crops having same season can be grouped together, paddy, which has a different hydrological response and water requirement, is classified into separate parcels.

Based on the land use data, cropping pattern details, and crop wise irrigated area in different years, area under the following land-use parcels, as shown in Table 12, were derived by trial and error process and used in the study.

The composition of land parcels is shown in Figure 6.

2.4 Results of Model Calibration

The model has been run on monthly basis, for ‘average’ rainfall conditions for the past and all future scenarios. The present situation is however studied for the average, bad and good rainfall conditions, to understand changes

Table 11
Estimates of Flows/ Assembled from Observed for Sub basins (10^6 m^3)

Year	SB1 ^a (10,050 km ²)	SB2 ^b (4,363 km ²)	SB3 ^c (7,152 km ²)	Total basin (21,565 km ²)
1995-96	38.41	142.84	105.33	286.58
1996-97	141.75	197.81	559.70	899.26
1997-98	1318.97	1857.94	2464.29	564.20
1998-99	345.44	645.18	466.29	1456.87
1999-2000	20.67	57.29	1945.67	272.63
Average	373.05	580.21	758.04	1711.31

^a : Proportionate from the observed flows at Gandhinagar G&D Sites

^b : Proportionate from the total observed flows at Dabha, Ambadiyara and Minamuda, G&D Sites

^c : Proportionate from the total of observed flows at Bhilodra and Mehamadabad, G&D Sites

Table 12
Description of Land Use Parcels

Parcel Designation	Description
P1	Forest and miscellaneous trees
P2	Permanent pastures
P3	Land not available for cultivation, waste, & fallow
P4	Land under reservoirs and other water bodies
P5	Kharif Paddy (rain-fed) only
P6	Rainfed two seasonals (kharif and rabi)
P7	Rainfed perennials
P8	Rainfed other kharif and rabi and fallow in hot weather
P9	Rainfed other kharif and fallow in rabi and hot weather
P10	Rain-fed other kharif, Irrigated rabi, and fallow in hot weather
P11	Irrigated kharif paddy and fallow in rabi and hot weather
P12	Irrigated perennials
P13	Irrigated two seasonals (kharif-rabi) and fallow in hot weather
P14	Irrigated two seasonals (rabi and hot weather)
P15	Irrigated other kharif, irrigated rabi and fallow in hot weather
P16	Fallow in Kharif, irrigated rabi and irrigated hot weather
P17	Fallow in Kharif, irrigated rabi and irrigated hot weather paddy
P18	Fallow in kharif, irrigated rabi and fallow in hot weather
P19	Irrigated kharif and fallow in rabi and hot weather
P20	Irrigated kharif (other crops), fallow in rabi, and irrigated in hot-weather

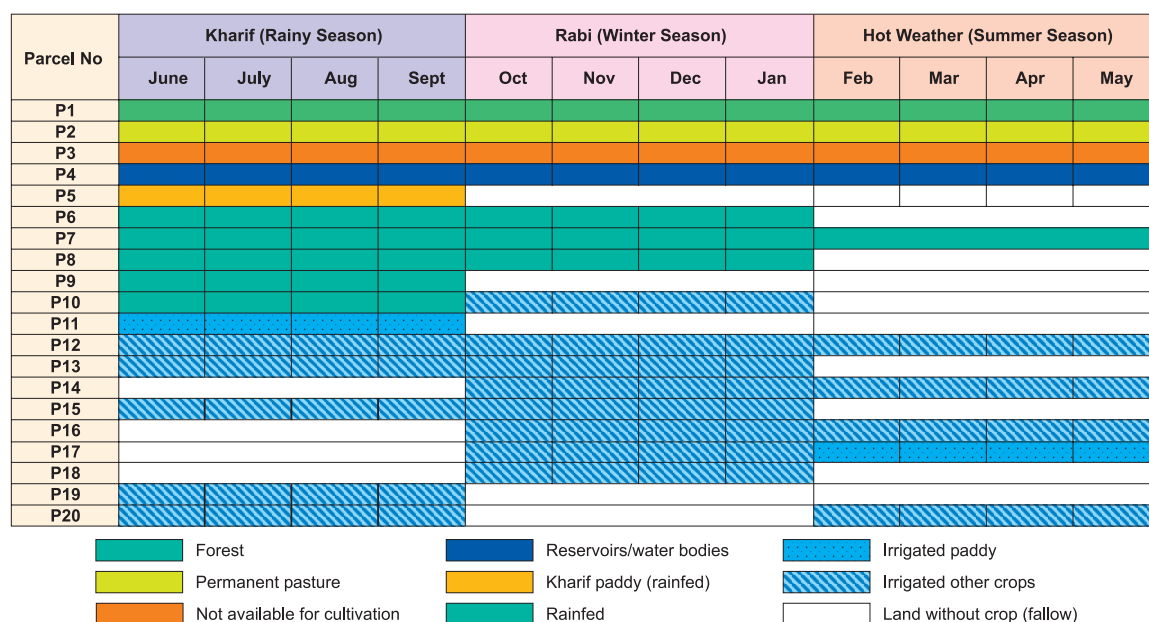


Figure 6 Composition of Land Parcels and their Temporal Coverage

in the model behaviour with rainfall regime, and allow its comparison with the observed variability. Rigorous calibration and validation of the model has not been aimed at for the present. The model is also meant mainly for finding the relative impacts of future scenarios in regard to land and water use on the basin hydrology, and thereby to understand the policy implications, and not for drawing detailed basin/ sub basin plan for implementation.

The task has been therefore limited to getting the model response so as to reasonably fit with the ground situation by adopting following steps.

- Comparing the outflow of SB1 with the estimate of observed runoff based on the observations of the Sabarmati at Gandhinagar.
- Comparing the outflow of SB2 with the estimate of observed runoff built up by proportioning the addition of Watrak at Dabha and Mazam at Ambadiyara, a little downstream of SB2.
- Comparing the total model output with the estimate of observed runoff from that of SB1, SB2 as also the downstream of (SB3) from the observation of Shedi at Bilodra and Watrak at Mehamadabad.
- Comparing the range of intra-annual as also inter annual groundwater fluctuation, with the known groundwater fluctuation.
- Comparing the natural recharge to groundwater as in the model, as a percentage of rainfall, and to compare this percentage with the generally adopted norms.
- Comparing the total groundwater recharge and withdrawal, as computed by the model, with the estimates of the Gujarat State Groundwater Agency.
- Inter comparing the annual variability of the runoff of Sabarmati river in good, average and bad years.

The BHIWA model calibration can normally be done for a single average year. This approach was followed initially, but some experts expressed, during the 'National Consultations' that the calibration needs to be improved and needs to reflect observed regime. Therefore, considering that the Sabarmati river flows were extremely variable, the calibration has been done on a monthly basis for a five-year period (1995-96 to 1999-2000). This allows a sequential continuous operation of the model, including

the storages in the soil and groundwater. Rainfall data of the individual year was used. However, ET_0 and land use of individual years were not available, and monthly averaged values of ET_0 and average land use for the 5 years have been used in the simulation.

The approximate comparison of surface flows computed by the model (with natural recharge from river to Groundwater) with the observed flows at nearby river gauge and discharge sites is as follows:

Table 13
Comparison of Computed and Observed Flows ($10^6\text{m}^3/\text{year}$)

Sub-basin/ Basin	Average flow computed by the model	Observed flow (estimated) at the outlet of sub basin
SB 1	358	373 (Indira Bridge)
SB 2	1075	580 (Watrak at Khera)
Total basin (including SB3)	1933	1711

The comparison of observed and computed flows at the outlet of SB3 is shown in Figure 7. This indicates that the river flows as computed by the model are similar to those observed, in their characteristics about the shape of the hydrographs.

The calibration results in regard to the flows are abstracted in Table 14 below.

Table 14
Calibration Results in Regard to River Flows (10^6 m^3)

Sub-basin/ Basin	Average of monthly flows 1995-96		Percentage variance (as explained in the monthly series)
	Observed	Computed	
SB 1	31.09	34.85	25.1
SB 2	134.6	206.8	70.2
Total basin	142.6	168.8	80.3

Thus, for the total basin, the fit is reasonably good. For sub-basin 1, the average bias is small, but the residual variance is large. The position is reversed for sub-basin 2.

One of the reasons for the variation could be that the

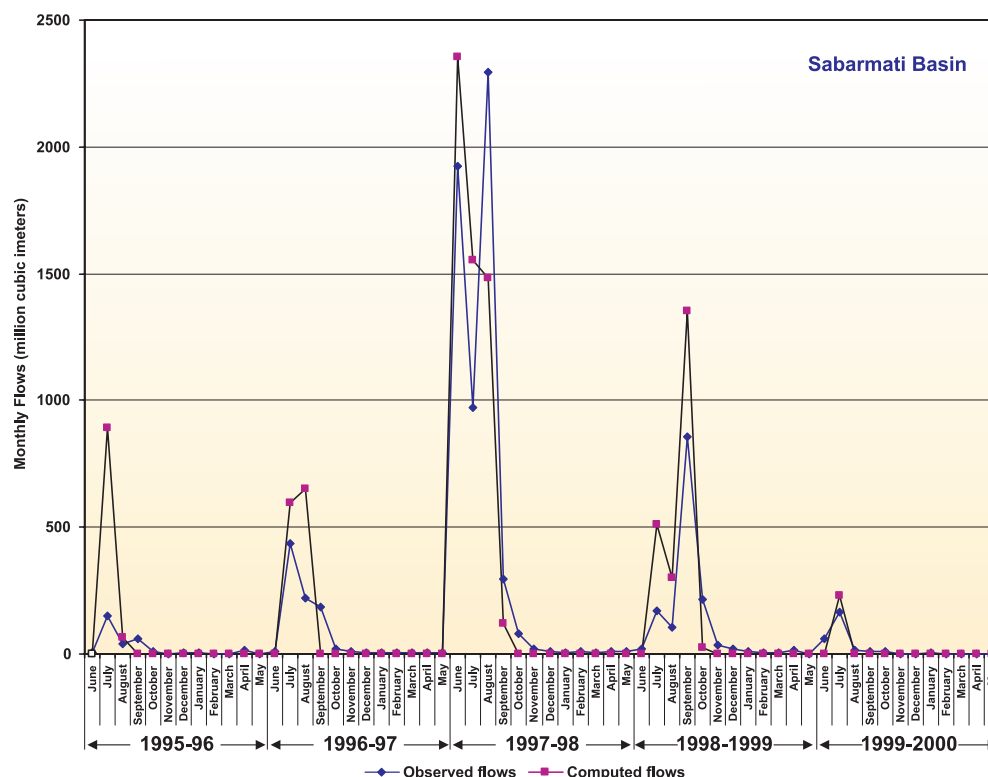


Figure 7 Comparison of Observed and Computed River Flows

rainfall in the concurrent observation period was about 10 percent less than the long-term average used in the model.

The groundwater regime as resulting from the calibration is abstracted in Table 15.

This ground water regime, in general, is similar to what occurred in the basin. Available water table data for the years 1991, 2001 and 2002 for 115 observation wells spread over the entire basin and 59 piezometers mostly located in the lower parts were analysed for calculating changes in

seasonal and inter-annual groundwater storage. The basin was divided into two parts representing hard rock areas of the upper basin and alluvial areas of lower portion. The change in storage corresponding to the three sub-basins is given in Table 16. The average change over the ten year period using pre-monsoon (May) and post monsoon (October) readings for the basin as a whole works out to about (-) 332 million cubic meters per year as detailed in Table 17.

Table 15
Calibration Results in Regard to Groundwater Regime

Indicators	Sub-basin 1	Sub-basin 2	Sub-basin 3	Remarks
Total recharge, as a % of Rainfall	16.8	16.85	16.85	
Total recharge as depth over sub-basin (m)	0.094	0.21	0.095	These depths in meters are in terms of the depths of a water column. Depending on the specific yields, the actual fluctuations would be far larger.
Intra-annual fluctuation as depth over sub-basin (m)	0.12	0.15	0.06	
Inter-annual trend, changes in groundwater depth over sub-basin per year (m)	(-) 0.10	(-) 0.03	(-) 0.13	

Table 16
Change in Groundwater Storage

Sub-basin	Type of Formation	Area Km ²	Specific Yield	Change in GW Storage (10 ⁶ m ³)				
				May 1991 to Oct. 1991	Oct. 1991 to May 2001	May 2001 to Oct. 2001	Oct. 2001 to May 2002	May 2002 to Oct. 2002
1(a)	Alluvial	2,529.5	0.07	276.36	-859.46	303.03	-216.72	184.87
1(b)	Hardrock	6,836.38	0.03	185.04	-1,375.3	727.8	-648	-44.4
2(a)	Alluvial	511.5	0.05	98.15	-178.2	32.45	-73.55	48
2(b)	Hardrock	3,629.75	0.02	210.28	-474.28	143.12	-160.52	91.56
3(a)	Alluvial	6,655.38	0.06	681.78	-1,814.8	309	-930.6	677.82
3(b)	Hardrock	1,113.25	0.02	77	-175.58	72.82	-70.12	42.58
Basin	Alluvial	9,696.38		1,056.29	-2,852.4	644.48	-1,220.9	970.69
	Hardrock	11,579		472.68	-2,025.1	943.74	-878.64	89.74
Total Basin		21,276		21,276	-4,877.5	1,588.22	-2,099.5	1,000.43

Table 17
Change in Groundwater Storage between 1991-2001
(10⁶ m³)

	October 1991 to October 2001	May 1991 to May 2001	Average
Alluvial Areas	2,208.0	1,796.11	2,002.05
Hard Rock Areas	1,081.3	1,552.42	1,316.86
Total	3,289.3	3,348.52	3,319.91

The general decline is supported by the time series data plotted for a few randomly selected observation wells in Figures A4 to A8, depicting unsustainable trend in groundwater use. Plans showing reduced water levels for October 1991 and October 2001 are given in Figures 16 and 17. Due to steep groundwater gradients and the scale of the map this trend is not so clearly evident on the above maps.

The general validation of the model is fair enough with the following values of main parameters:

- Soil moisture storage capacity varies with soil type and land use. It was estimated as 200 mm for forests, 100 mm for permanent pasture, 75 mm for agricultural lands (but 150 mm for paddies), 50 mm for land not available for cultivation, and 30 mm for land under reservoirs. Higher capacity values would lead to higher evapo-transpiration and lower flows after rainfall has ceased, thus giving a better

calibration but values higher than these were not tried, since such capacities were unlikely to be available.

- The excess water was divided assuming 80 percent yields to surface and sub surface (or quick runoff) flow and the rest 20 percent yield to groundwater. With this assumption, reasonable annual recharge was realised.
- The proportionality index, depicting the exponential reduction of soil moisture with reducing availability in the relationship was kept at 1.0.
- A groundwater recession coefficient of 0.25 per month allowed the persistence of good base-flows, in the absence of withdrawals, up to say February, as was experienced in the prototype in the past. Currently, with very high groundwater withdrawals, especially in Sub-basins 1 and 3, base-flow ceases much earlier, both in the prototype and in the model.
- Additional evapo-transpiration needs, which are met through irrigation (deficit irrigation supply factor) came to around 90%.
- Irrigation system variables for present conditions used are given in Table 18.
- Values of other variables relating to surface and groundwater irrigation systems are listed for the present as well as Future scenarios in Table 21.

Table 18
Irrigation System Variables and Constants Used in Present Scenario

Components	Present (1995)
Proportion of return flows evaporating through water logged areas and swamps from surface irrigation	0.2
Proportion of residual return flows returning to surface waters from surface irrigation	0.2
Proportion of residual return flows returning to ground waters from surface irrigation	0.8
Proportion of return flows evaporating through water logged areas and swamps from GW irrigation	0.05
Proportion of residual return flows returning to surface waters from GW irrigation	0.05
Proportion of residual return flows returning to ground waters from GW irrigation	0.95
Surface water conveyance and distribution efficiency.	0.4
Ground water conveyance and distribution efficiency.	0.7
Proportion of additional evapo-transpiration needs which would be met through irrigation	0.9

2.5 Development of Scenarios

The scenarios studied included emerging possibilities, developmental plans on anvil, adoption of improved water and soil management practices etc. However, neither a major shift from water intensive crops nor changes in livelihood pattern and food imports from other basins etc. were considered. There is little possibility of increasing storages in Sabarmati basin. Even, the available storage in sub-basin 1 and sub-basin 2 do not fill up.

There are plans and possibilities of large imports from the Narmada river. The Gujarat State Government has also prepared a plan for using monsoon surpluses from the Narmada river, for pumping and filling of the high level storages, including those in Sub Basin 1 and Sub Basin 2. Although, there could be pros and cons of these plans; the possibility itself needed a review. Similarly, a possibility of constraints on imports due to inter-state issues also exists and this also needs to be explored. Scenarios F-III, F-IV and F-VI were developed for this purpose.

The 'present' irrigation, with stress on post wet season (Rabi) irrigation is causing large reduction in minimum river flows, and hence the idea of changing the emphasis and having increased irrigation in wet season (Kharif)

instead of post wet season has been contemplated in some of the scenarios. In particular, scenario F-V to F-VIII incorporated this strategy.

Similarly, groundwater is the predominant source of irrigation in the Sabarmati river basin. It is already over-exploited. If this trend continues with Business as Usual (B as U), the situation becomes totally unsustainable. Hence, a comparative reduction in groundwater use has been studied in scenario-VI.

Improved water management through improving irrigation system efficiency, evaporation and evapo-transpiration control by measures like mulching; weeding of barren areas and increased area under micro-irrigation are important strategies. This is contemplated in scenario-VII.

Since large changes in water management practices and large shifts in cropping seasons may be difficult to implement, a scenario, which effects some changes in a somewhat moderate way, was also built up. This is scenario VIII.

Considering these factors, various scenarios studied were formulated and are shown in the Table 19. The model was run using the long-term average rainfall.

The description of each scenario are given below:

1. Past (1960)

The data for this scenario was assembled from the old district gazettes of about 1961-62 as obtained by the Gujarat state team.

In this scenario land under agriculture was 1.103 Million ha. and irrigated area was 0.11 Million ha. Irrigation development consisted mainly of groundwater use and few small surface water projects. This scenario can help setting up of reference for minimum flows for maintenance and enhancement of ecology and environment of the basin.

2. Present (1995)

In this scenario land under agriculture was 1.234 Million ha. and area under irrigation was 0.629 Million ha. Irrigation development has taken place, (i) through construction of Dharoi, Hathmati, Watrak, Harnav, Guhai, Mazam, Meshwa and the Wasna projects. (ii) Import from Mahi (1,580 million cubic meter) water through Mahi Right Bank canal (iii) large increase in groundwater exploitation. The export was 260 million cubic meters.

Table 19
Brief Description of the Scenarios

S.No.	Scenarios	Key attributes	Brief description
1.	Past	1960	Irrigation development mainly from groundwater use and minor irrigation projects.
2.	Present	1995	Major part of the water resources development took place due to construction of number of reservoirs and import from Mahi and groundwater irrigation.
3.	F-I	2025 - B as U - with Narmada import	Irrigation expansion with proportionate increase in surface irrigation due to Narmada import and groundwater irrigation.
4.	F-II	2025 - B as U -Without Narmada import	Same as F-I without Narmada import.
5.	F-III	2025 - Gujarat Plan	Agricultural plan same as F-I. Imports and exports as per Gujarat State Plan which envisages import of 2,358 million cubic meter of Narmada waters for filling of surface reservoirs in sub basin 1 and sub basin 2 to meet present gaps in supply and future irrigation expansion, including export from ex-Wasna and Dharoi storages, for 1,415 million cubic meter and completion of ongoing irrigation schemes.
6.	F-IV	2025 - Less import and less export	To attain matching with availability of water within the basin, reduction in irrigated area and less import and export.
7.	F-V	2025 - Seasonal shift in Agriculture	Irrigation expansion accompanied by shift in cropping pattern to have more irrigated area in kharif and less irrigated area in rabi.
8.	F-VI	2025 - Reduction of groundwater	Reduction of ratio of groundwater irrigation to total irrigation, some pumping of Narmada waters to reservoirs in sub basin 1 and sub basin 2.
9.	F-VII	2025 - Better water management	Reduction in groundwater irrigation. Better water management by introducing micro irrigation and removal of unwanted bushes in the barren lands.
10.	F-VIII	2025 - Shift to kharif irrigation and larger exports	Limited irrigated area, shift towards kharif. Larger ex-Wasna exports similar to Gujarat plan. Attempts to reduce groundwater imbalance - induced recharge from river to groundwater as also pumping from groundwater to canals and providing a small environmental flow requirement.

3. Future-I (2025) Business as Usual

This scenario has been developed as Business as Usual (B as U). Considering that the Sardar Sarovar (Narmada) canal is ready up to Sabarmati and the import from Mahi and Narmada is 3,084 million cubic meters (1,580 million cubic meters from Mahi and 1,500 million cubic meters from Narmada). The export through the Dharoi and Wasna canals going beyond the basin is 425 million cubic meters. Land under agriculture (1.328 Million ha.), net irrigated area (0.995 Million ha.) and gross irrigated area (1.244 Million ha.) have been increased. In general, this scenario depicts a steady growth in uses, and additional imports and exports, without any large corrective action. In the scenario, the basin groundwater regime require to be made sustainable through large induced recharge from surface to

ground of about 2,120 million cubic meters and, a pumping of groundwater to surface canals of about 620 million cubic meters. Thus, the projected river flows were also low, and in particular, the river flows in low flow scenario were negligible. There is, therefore a need to develop more acceptable scenarios.

4. Future-II (2025) Business as Usual – without Narmada Import

The scenario was developed to study the state of the basin, in the event of a gradual expansion of the use, but without the benefit of additional imports from the Narmada. There is little possibility of such an eventuality, although the amount of import from Narmada could vary, as per the allocation of these within Gujarat, which are perhaps yet

to be decided. The very large need for “induced recharge” of ground and the low residual river flow indicates that this scenario is unlikely to be accepted by anyone.

There would be import of 1,580 million cubic meters from Mahi and no import from Narmada. The export will be 260 million cubic meters. The land under agriculture, net irrigated area and gross irrigated area are kept the same as in Future-I scenario.

5. Future-III (2025) - As per Gujarat Plan

This scenario, in general depicts the plan of action as proposed by Gujarat, in its white paper (GOG, 2000). A total import of 3,938 million cubic meters (1,580 million cubic meter from Mahi and 2,358 million cubic meters from Narmada). The plan involves the pumping of the surplus high flows in Narmada, to the upper reservoirs, like Dharoi, Hathmati etc, since there is an unused storage capacity in these reservoirs. Export has been increased to 1,415 million cubic meters against 425 million cubic meters in Future-I. Land under agriculture, net irrigated area and gross irrigated area are kept same as in Future-I scenario. Land under kharif is 0.559 Million ha. against 0.366 Million ha. proposed in scenario Future-I. Two seasonals and perennial crops have been reduced slightly. Narmada water was proposed to be pumped in the reservoirs of sub basin 1 and sub basin 2 to augment surface irrigation.

6. Future-IV (2025)

An import of 2,334 million cubic meters (Mahi 1,580 and Narmada 754) and export of 425 million cubic meters were considered in this scenario. The land under agriculture is same as in Future-I. The rain-fed area and irrigated area are 0.503 Million ha and 0.826 Million ha respectively against rain-fed area of 0.334 Million ha and irrigated area 0.995 Million ha in the scenario Future-I.

This scenario was developed to improve the situation for the Future I scenario, with only some reduction in irrigated areas and increase in rain-fed areas; but without large shifts in cropping patterns or cycles.

The results after ensuing sustainability showed only a small improvement in flows, and a substantial reduction in both the induced recharge and in pumping of groundwater to canals.

Though better than Future I, this scenario is perhaps still not very good.

7. Future-V (2025)

The Future V scenario was developed by incorporating

large shifts in the cropping patterns of irrigated crops, as compared to Future I, for obtaining more acceptable results.

An import of 3,084 million cubic meters and export of 425 million cubic meters were considered in this scenario as in the scenario Future-I. The land under agriculture, the net irrigated area and gross irrigated area, are also same as in scenario Future-I. The irrigated area in kharif has been raised to 0.830 Million ha. against 0.366 Million ha under 'Future-I'. The area under kharif two seasonals (kharif + rabi) has been reduced to 0.042 Million ha against 0.261 Million ha in scenario Future-I. The area under rabi two seasonals (rabi + hot weather) and perennial are not provided.

The results indicated that due to the shifts in cropping patterns, the river flows (both annual and the low flows) increased substantially as compared to the Future I (B as U). The need of inducing recharge from river to groundwater reduced very substantially to about 500 million cubic meters and the need for pumping groundwater to canals also reduced to about 290 million cubic meters.

Although the results indicated a much better state of the basin under this scenario, the practicability of these large shifts in cropping patterns, and the desirability of further reducing groundwater use required the development of additional scenario.

8. Future-VI (2025)

This scenario was developed as a compromise between the Gujarat Plan and the concept of shifting the irrigated cropping to the kharif, as in Future V. An import of 3,084 million cubic meters and export of 425 million cubic meters were considered in this scenario as in the scenario 'Future-I'. The area under agriculture and net and gross irrigated areas are same as in Future-I. Gross area under kharif is 0.830 Million ha against 0.366 Million ha in Future-I. Groundwater use is reduced. Narmada water is proposed to be pumped in the reservoirs of sub basin 1 and sub basin 2 to augment surface irrigation.

The results indicated that the need for induced recharge further dropped down to 200 million cubic meters, although the need for pumping groundwater to canals was similar to Future V. The river flows were somewhat similar to Future V.

9. Future-VII (2025)

This scenario included lesser irrigations, shift in irrigated crop season and improved water management. An import of 3,084 million cubic meters and export of 425 million cubic meters were considered in this scenario as in the

scenario Future-I. Land under agriculture is same as in Future-I. Rain-fed area is increased to 0.438 Million ha against 0.334 Million ha in Future-I. Correspondingly the irrigated area is reduced. The area under kharif two seasonals (kharif + rabi) has been reduced to 0.038 Million ha against 0.261 Million ha in scenario 'Future-I'. The area under rabi two seasonals (rabi + hot weather) and perennial are not provided. The surface and groundwater withdrawals for irrigation have been reduced by better water management and introducing micro irrigation for saving the water. The consumptive use for nature sector has been reduced by removal of unwanted bushes in the barren land.

The results indicated a further improvement in the river flows, and elimination of the need for inducing surface water to recharge ground waters. The need for pumping groundwater to canals, however increased (as compared to Future V).

10. Future-VIII (2025)

This scenario was developed by modifying Future V, so that the shift in irrigated cropping pattern from Rabi to Kharif is limited, to increase the achievability. An import of 2,834 million cubic meters against 3,084 million cubic meters was considered in this scenario as in Future-I. The export is 1,024 million cubic meters against 425 million cubic meters as in 'Future-I'. Land under agriculture is same in 'Future-I'. The rain-fed area is increased to 0.405 Million ha against 0.333 Million ha in 'Future-I'. Gross area under kharif has been increased to 0.552 Million ha, where as the area under Rabi and Hot weather two seasonals (rabi + hot weather) have been reduced. For this scenario, the model was tested for observing arbitrarily prescribed environmental flows at the outlet of the basin.

11. General

1. The areas in different land parcels in various scenarios are shown in Table 20. Proportion of area coverage by natural vegetation, rain-fed and irrigated agriculture in different scenarios is given in Figure 8. The net irrigated area (NIA) by source is shown in Figure 9.
2. The present studies are not aimed at choosing the future scenarios, but rather for demonstrating how the scenario could be developed and analysed.

However, in general, scenario Future I, Future II and Future III could be considered as steps in scenario building. The scenario Future IV, Future V, Future VI, Future VII and Future VIII could be considered as viable scenarios for choosing the more acceptable one.

2.6 Simulation of Different Scenarios

The model was applied to simulate for the 1960 conditions, when irrigation through surface and groundwater development was low, corresponding to the average rainfall year. The model was also used to simulate a modified version of the "present". As discussed, the present situation, as used in the calibration is not sustainable, since the estimated ground water recharge, at present, is less than the withdrawals plus the base flows. This was corrected and made sustainable by inducing recharge from the river flows to the ground water, in the wet months. Similarly, the model was used to simulate responses for all the future scenarios enumerated earlier with average rainfall. All these future scenarios were also made sustainable, through induced recharge, wherever necessary.

The abstracted results of annual overall water balance; annual river and surface water balance, and annual groundwater balance are presented in the Tables 22, 23 and 24 respectively. The annual water balance and ground water balance are also shown in Figures 10 and 11.

The consumptive use (evapo-transpiration) by sectors is shown in Table 25 and depicted in Figure 12. The composition of consumptive use in agriculture sector is depicted in Figure 13. The requirements of groundwater pumping into canals and natural recharge from river to groundwater are given in Table 26. Monthly river flows under various scenarios are provided in Table 27 and selected three scenarios are also shown graphically in Figure 14. Composition of water withdrawals and returns in different scenarios are shown in Table 28 and also is depicted in Figure 15. Land use, import and export in different scenarios are shown in Table 29.

2.7 Discussion of Results

Based on the 'present' (1995) conditions and average rainfall, the model response for sustainable water use (without over exploitation of groundwater for use) conditions is briefly described below:

- a) The 'present' scenario, as worked out in the simulation mode is slightly different from the calibration scenario. In the present scenario, the rainfall used is long-term average, and not the actual in the years of calibration. Similarly, the present scenario is made sustainable in regard to groundwater, by eliminating the inter-annual fluctuation through induced recharge where necessary. The present scenario shows a river outflow of 2,686 million cubic meters under the sustainable condition.

Table 20
Area of Land Parcels in Different Scenarios (km²)

Category of Parcel	Past (1960)	Present (1995)	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
P1	4097	4097	4097	4097	4097	4097	4097	4097	4097	4097
P2	996	996	789	789	789	789	789	789	789	796
P3	5446	3985	3250	3250	3250	3250	3250	3250	3250	3201
P4	0	150	150	150	150	150	150	150	150	150
P5	1116	558	320	320	143	471	0	0	0	558
P6	1300	556	246	246	173	430	120	120	120	556
P7	0	35	27	27	8	34	0	0	0	35
P8	0	451	146	146	1630	322	2759	2759	3229	251
P9	7500	4444	2593	2593	1377	3767	480	480	1050	2650
P10	0	806	1309	1309	665	1113	0	0	0	596
P11	120	1705	2686	2686	2660	2186	1500	1500	1360	2586
P12	0	379	595	595	408	495	0	0	0	379
P13	190	1640	2604	2604	1773	2169	420	420	380	1510
P14	0	110	169	169	140	139	0	0	0	21
P15	400	544	825	825	585	694	400	400	360	1070
P6	0	966	1518	1518	976	1260	0	0	0	300
P17	0	92	143	143	143	116	0	0	0	14
P18	400	49	98	98	398	83	1200	1200	1020	949
P19	0	0	0	0	1500	0	4500	4500	4050	1655
P20	0	0	0	0	700	0	1900	1900	1710	191
Total	21565	21565	21565	21565	21565	21565	21565	21565	21565	21565

Table 21
Irrigation System Variables and Constants Used in all Scenarios

Components	Past	Present	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Proportion of return flows evaporating through water logged areas and swamps from surface irrigation	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Proportion of residual return flows returning to surface waters from surface irrigation	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Proportion of residual return flows returning to ground waters from surface irrigation	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Proportion of return flows evaporating through water logged areas and swamps from GW irrigation	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Proportion of residual return flows returning to surface waters from GW irrigation	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Proportion of residual return flows returning to ground waters from GW irrigation	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Surface water conveyance and distribution efficiency.	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Ground water conveyance and distribution efficiency.	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Proportion of additional evpo-transpiration needs which would be met through irrigation	1	0.9	1	1	1	1	1	1	0.85	0.9

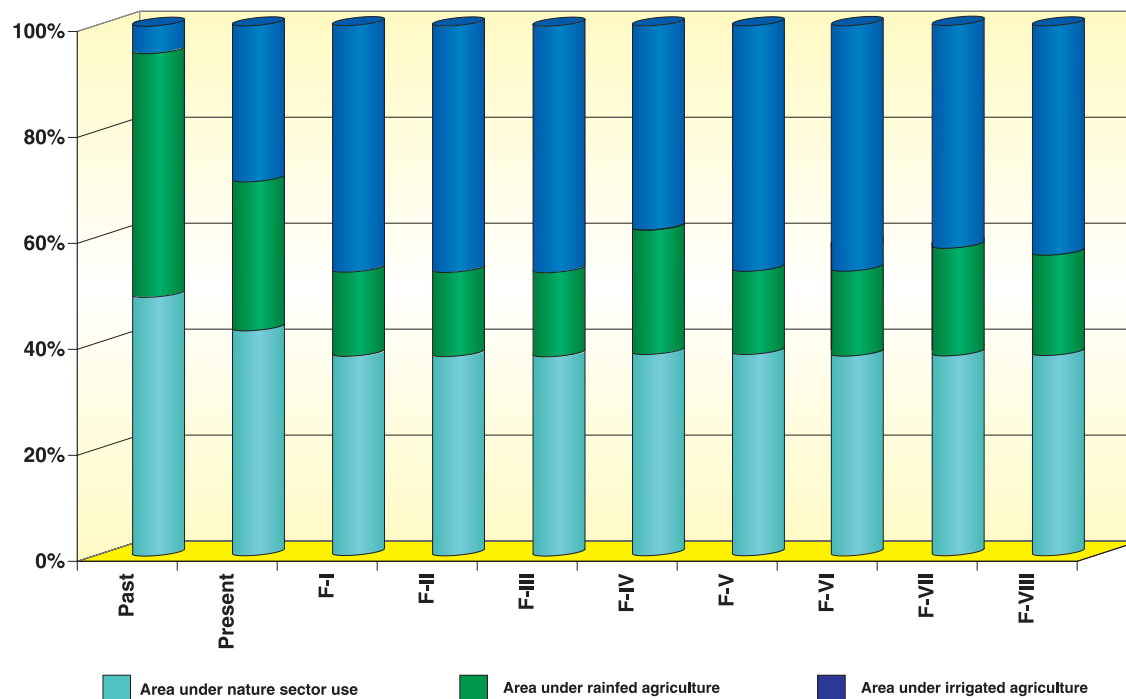


Figure 8. Area Coverage by Natural Vegetation, Rainfed and Irrigated Agriculture

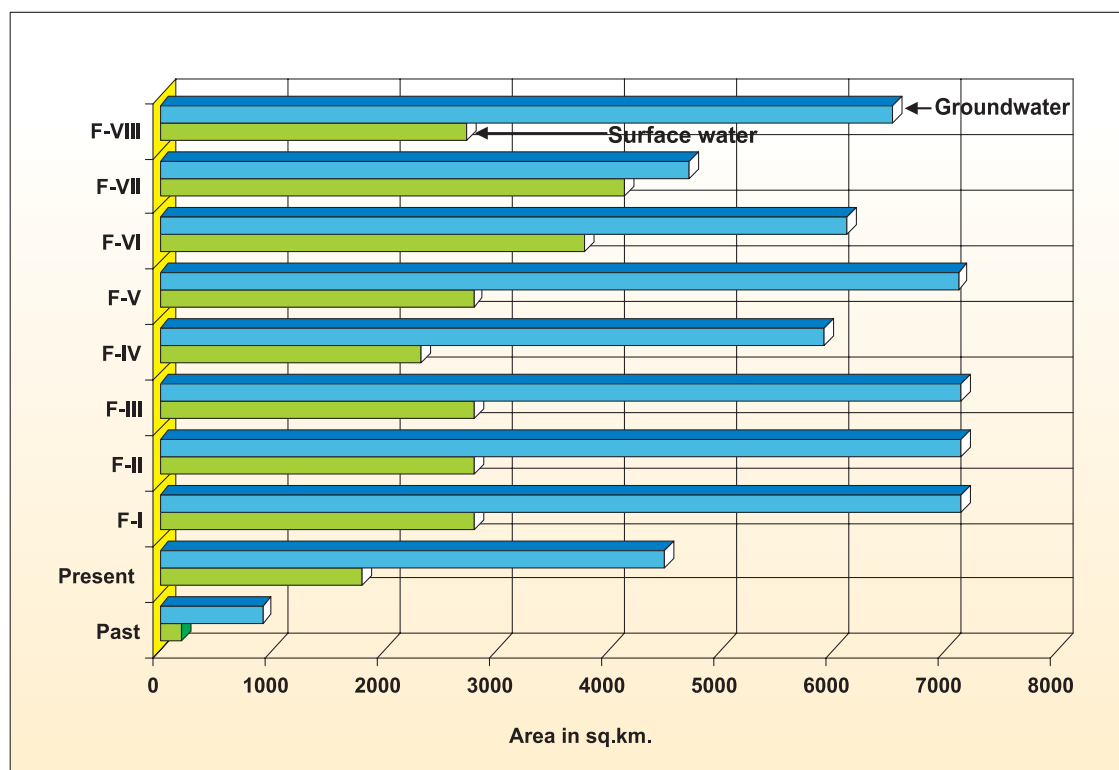


Figure 9. Net Irrigated Area by Source

Table 22
Annual Overall Water Balance (10⁶ m³)

Component	Past (1960)	Present (1995)*	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Inputs										
Rainfall	16,162	16,160	16,164	16,164	16,164	16,162	16,162	16,162	16,143	16,164
Imports	0	1,584	3,084	1,581	3,938	2,334	3,084	3,084	3,081	2,834
Groundwater flow from other basins	0	0	0	0	1	0	0	0	0	0
Total inputs	16,162	17,744	19,248	17,745	20,103	18,496	19,246	19,246	19,224	18,998
Outputs										
Consumptive use total	11,833	14,796	17,519	17,524	16,795	16,569	14,814	14,878	14,191	15,209
River flows total	4,329	2,686	1,302	-40	1,888	1,501	4,006	3,942	4,607	2,750
Export (surface)	0	260	425	260	1,417	425	425	425	425	1,024
Groundwater flow to other basins	0	0	0	0	0	0	0	0	0	0
Direct groundwater flow to sea	0	0	0	0	0	0	0	0	0	0
Total output	16,162	17,743	19,246	17,744	20,100	18,495	19,245	19,245	19,223	18,984
Storage changes										
Surface storages	0	0	0	0	0	0	0	0	0	0
GW storage	-1	0	2	-1	0	0	0	0	0	0
Total storage change	1	1	2	1	2	1	1	1	1	2
Imbalance	0	0	0	0	1	0	0	0	0	13
Soil Moisture Storage Change	1	2	2	2	2	2	1	1	1	2

* Adjusted to sustainable water use conditions/stable hydrologic regime.

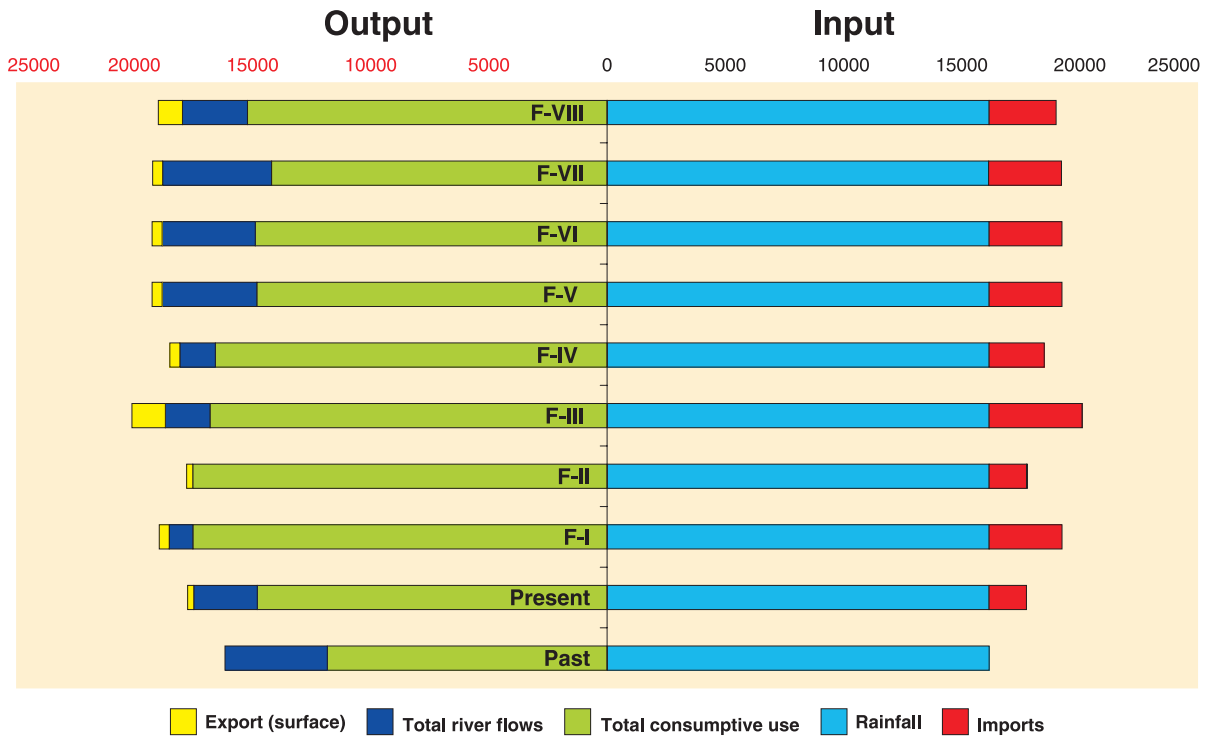


Figure10. Annual Overall Water Balance

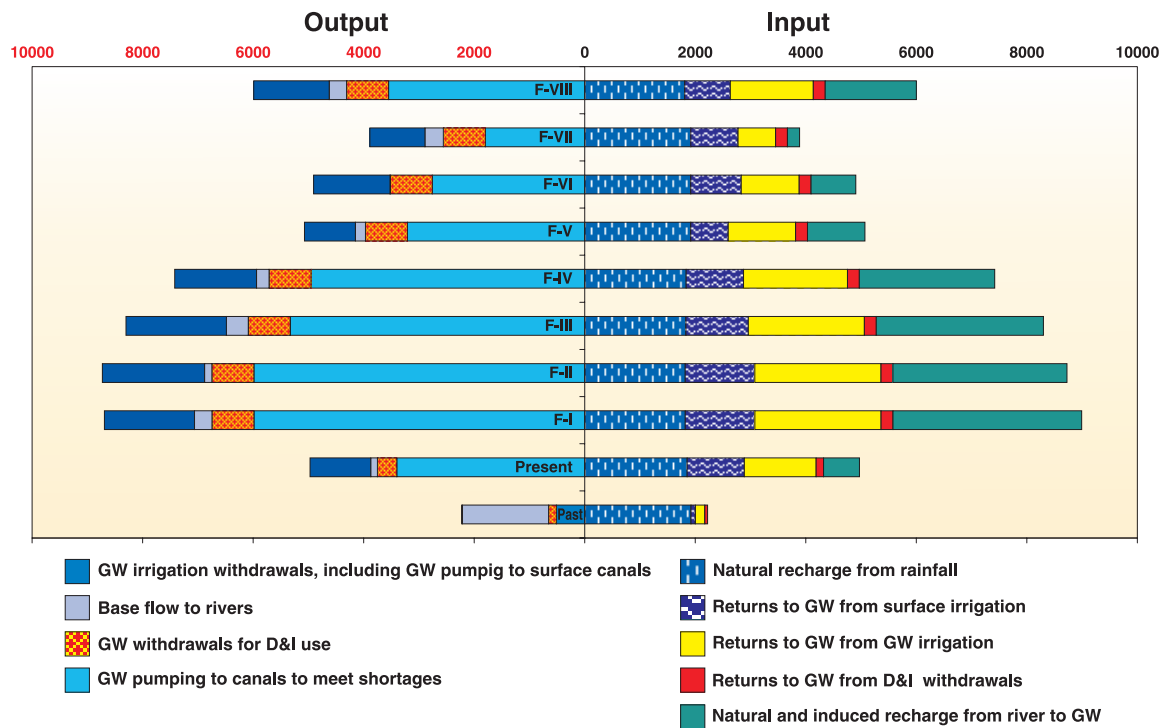


Figure 11 Annual Groundwater Balance (million cubic meters)

Table 23
Annual River and Surface Water Balance (10⁶ m³)

Component	Past (1960)	Present (1995)*	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Inputs										
Quick runoff from rainfall	2,884	2,781	2,730	2,729	2,746	2,754	2,877	2,877	2,878	2,715
Base flow	1,562	122	648	132	396	227	182	5	334	314
Returns to surface from surface irrigation	20	259	315	315	283	259	170	229	214	206
Returns to surface from GW irrigation	9	68	120	120	111	99	64	55	36	79
Returns to surface from D&I withdrawals	61	196	937	937	937	937	937	937	937	937
Sub-total, returns to surface	90	523	1,372	1,372	1,330	1,295	1,171	1,221	1,187	1,222
Imports	0	1,584	3,084	1,581	3,938	2,334	3,084	3,084	3,081	2,834
Total inputs	4,536	5,010	7,834	5,813	8,410	6,611	7,314	7,187	7,480	7,085
Outputs										
Surface withdrawals for irrigation in the basin	183	1,304	1,726	1,477	1,114	1,268	875	1,043	1,262	694
Surface withdrawals for D&I in the basin	25	109	967	967	967	967	967	967	967	967
Total surface withdrawals, for use in the basin	207	1,413	2,693	2,444	2,080	2,235	1,842	2,010	2,229	1,660
Natural and induced recharge from river to GW	0	650	1,302	3,150	3,025	2,450	1,040	810	220	1,650
Outflow to sea	4,329	2,686	1,000	-40	1,888	1,501	4,006	3,942	4,607	2,750
Export	0	260	425	260	1,417	425	425	425	425	1,024
Total output	4,536	5,010	7,834	5,813	8,410	6,611	7,314	7,187	7,480	7,085
Storage change	0	0	0	0	0	0	0	0	0	0
Imbalance	0	0	0	0	0	0	0	0	0	0

* Adjusted to sustainable water use conditions/stable hydrologic regime.

Table 24
Annual Groundwater Balance (10⁶ m³)

Component	Past (1960)	Present (1995)*	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Inputs										
Natural recharge from rainfall	1,923	1,854	1,820	1,819	1,831	1,836	1,918	1,918	1,919	1,810
Returns to GW from surface irrigation	79	1,035	1,259	1,259	1,130	1,038	679	915	856	825
Returns to GW from GW irrigation	171	1,299	2,284	2,284	2,100	1,881	1,219	1,048	679	1,502
Returns to GW from D&I withdrawals	51	134	215	215	215	215	215	215	215	215
Sub-total, returns to GW	301	2,467	3,757	3,758	3,445	3,133	2,113	2,178	1,750	2,543
Natural and induced recharge from river to GW	0	650	3,415	3,150	3,025	2,450	1,040	810	220	1,650
Groundwater flow from other basins	0	0	0	0	1	0	0	0	0	0
Total inputs	2,224	4,971	8,993	8,727	8,302	7,419	5,071	4,906	3,889	6,002
Outputs										
GW irrigation withdrawals, including GW pumping to surface canals	522	4,499	7,585	7,836	7,145	6,433	4,129	4,141	2,794	4,916
GW withdrawals for D&I use	141	350	760	760	760	760	760	760	760	760
Sub-total GW withdrawals	662	4,849	8,345	8,596	7,905	7,193	4,889	4,901	3,555	5,676
Base flow to rivers	1,562	122	648	132	396	227	182	5	334	314
Groundwater flow to other basins	0	0	0	0	0	0	0	0	0	0
Direct groundwater flow to sea	0	0	0	0	1	0	0	0	0	0
Total outputs	2,224	4,971	8,993	8,728	8,302	7,420	5,071	4,906	3,889	5,990
GW storage change	-1	0	0	-1	0	0	0	0	0	0
GW imbalance	0	0	0	0	0	0	0	0	0	12

* Adjusted to sustainable water use conditions/stable hydrologic regime.

Table 25
Consumptive Use (ET) for Different Scenarios by Use Sectors (10⁶ m³)

Component	Past (1960)	Present (1995)*	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Nature sector										
Beneficial	3,411	3,410	3,293	3,293	3,293	3,293	3,293	3,293	3,293	3,295
Non beneficial	2,475	1,814	1,477	1,478	1,477	1,477	1,477	1,477	1,477	1,456
Total	5,886 (49%)	5,224 (35%)	4,770 (27%)	4,771 (27%)	4,770 (28%)	4,770 (29%)	4,770 (32%)	4,770 (32%)	4,770 (34%)	4,751 (31%)
Agriculture sector										
Beneficial	5,091	7,995	10,407	10,411	9,759	9,615	8,085	8,085	7,515	8,402
Non-beneficial	802	1,447	1,767	1,768	1,691	1,609	1,384	1,448	1,331	1,481
Total	5,893 (50%)	9,442 (64%)	12,174 (70%)	12,179 (70%)	11,450 (68%)	11,224 (68%)	9,469 (64%)	9,533 (64%)	8,846 (62%)	9,883 (65%)
People Sector										
D&I	54 (1%)	130 (1%)	575 (3%)	575 (3%)	575 (4%)	575 (3%)	575 (4%)	575 (4%)	575 (4%)	575 (4%)
Total	11,833	14,796	17,519	17,525	16,795	16,569	14,814	14,878	14,191	15,209

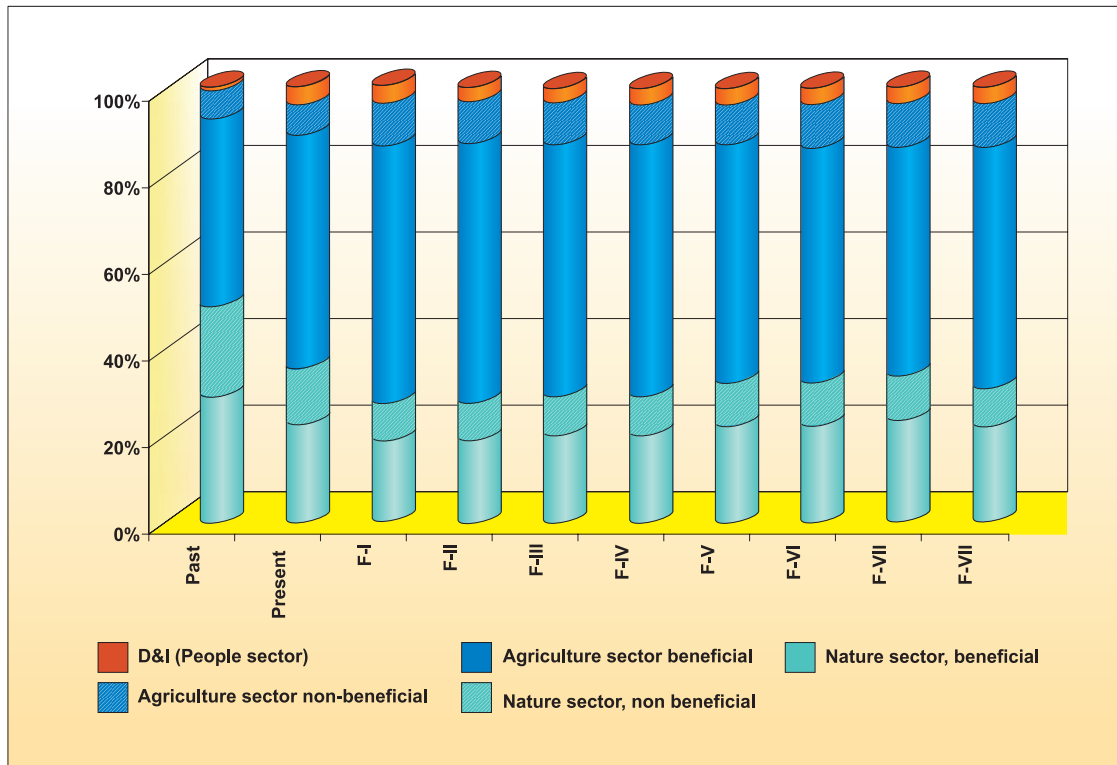


Figure12. Consumptive Use by Different Sectors

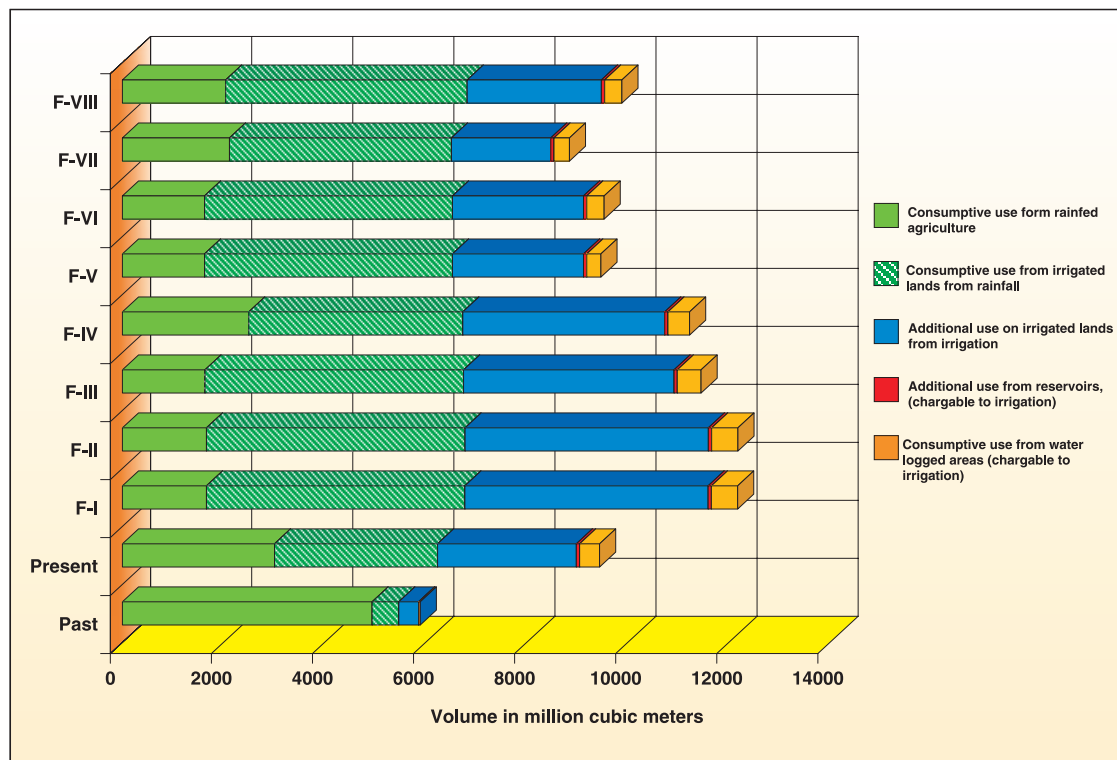


Figure 13. Composition of Consumptive Use in Agricultural Sector

Table 26
Requirements of Natural and/or Induced Recharge from River to Groundwater and Groundwater Pumping into Surface Canals Under Various Scenarios (10^6m^3)

Description	Past (1960)	Present (1995)	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Natural & induced recharge from river to Groundwater	0	650	3,415	3,150	3,025	2,450	1,040	810	220	1,650
Groundwater pumping to surface canals for meeting shortages in surface irrigation	9.99	1,099	1,600	1,850	1,818	1,482	922	1,383	997	1,367

Table 27
Monthly River Flows in Different Scenarios (10^6 m^3)

Component	Past (1960)	Present (1995)	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
June	7	0	55	0	0	0	157	0	91	5
July	663	383	352	22	408	293	901	847	899	286
August	2,307	2,103	532	130	1,082	939	2,067	2,153	2,848	1,570
September	467	102	169	-149*	267	171	547	865	550	324
October	308	-37*	94	-78*	77	3	59	-34*	78	207
November	206	-44*	68	0	25	0	13	-22*	31	7
December	134	-6*	0	0	0	0	21	9	9	5
January	73	20	0	0	0	0	56	38	21	5
February	63	65	31	35	0	48	76	62	52	48
March	46	39	0	0	13	22	45	14	13	100
April	33	39	0	0	15	23	41	9	14	99
May	23	22	0	0	0	2	24	0	0	92

* This denotes small negative flow (which are not possible) and resulting from limited iterations available in the programme.

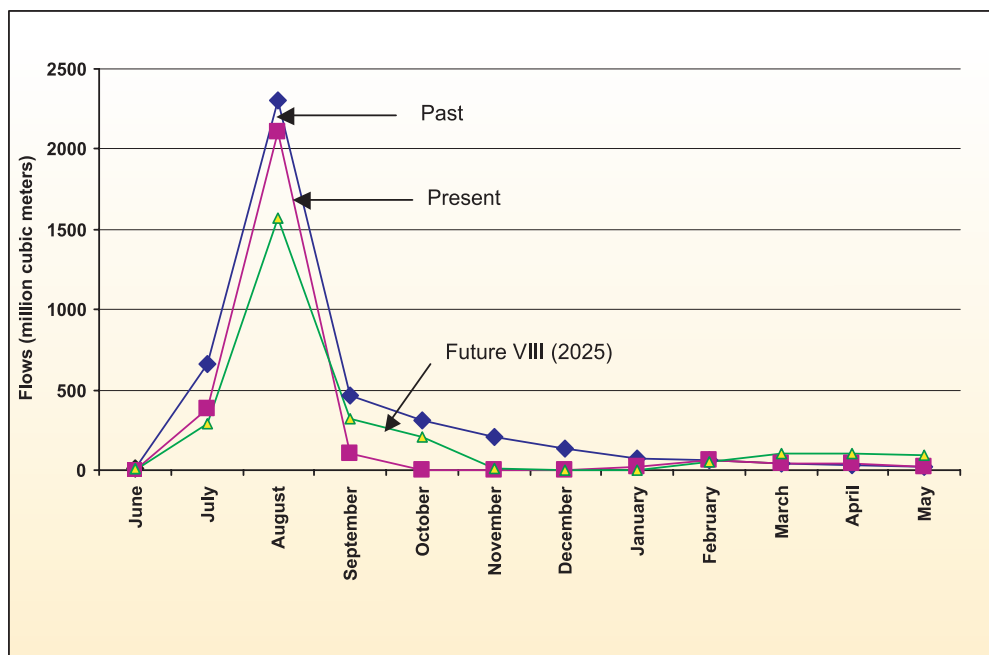


Figure 14. Monthly River flows in Selected three Scenarios

Table 28
Composition of Water Withdrawals (10^6 m^3)

Component	Pas (1960)	Present (1995)	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Surface water, withdrawal for irrigation in basin	183	1,304	1,726	1,477	1,114	1,268	875	1,043	1,262	694
Surface water withdrawal for exports, for irrigation, outside basin	0	260	425	260	1,417	425	425	425	425	1,024
Total surface withdrawal for irrigation including exports	183	1,564	2,151	1,737	2,531	1,693	1,300	1,468	1,687	1,718
Total surface withdrawal, including exports and D&I	207	1,673	3,118	2,704	3,291	2,660	2,267	2,435	2,654	2,684
Total groundwater withdrawal for irrigation including pumping to canals	522	4,499	7,585	7,836	7,145	6,433	4,129	4,141	2,794	4,916
Total groundwater withdrawal, for irrigation, pumping and D&I	662	4,849	8,345	8,596	7,905	7,193	4,889	4,901	3,555	5,676

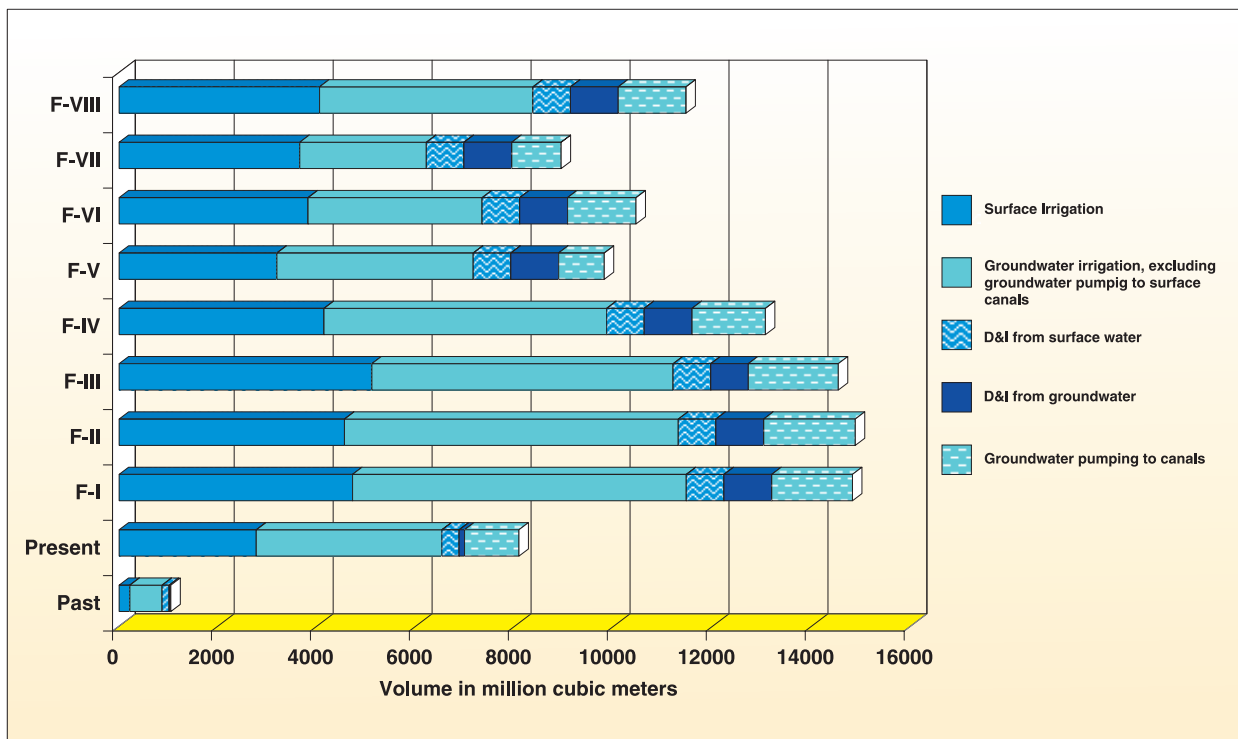


Figure 15. Composition of Water Withdrawals

b) The withdrawals required for sustaining the agricultural uses and the domestic and industrial uses for the present scenario are 1,673 million cubic meters from surface water and 4,849 million cubic meters from groundwater respectively. In 2025 (F-I), these withdrawals will be 3,118 million cubic meters and 8,345 million cubic meters respectively. These withdrawals could be facilitated, or made possible, by

- Filling of existing surface storages to the extent of 800 million cubic meters from Narmada, and
- Import from Mahi and Narmada waters.

c) The average inter-annual fluctuations of groundwater table indicated by the model vary from 1.91 m to 2.78 m. This appears to fit with observations in general.

d) The present total recharge from normal rainfall for the basin is estimated by the model as 1,854 million cubic meters, which is about 13 percent of average annual rainfall of 16,162 million cubic meters. For the 5 years calibration period, the total recharge was

about 15.8 percent of the rainfall in that period. This appears reasonable, and fits with estimates of other agencies. However, to obtain stable groundwater regime, an induced recharge from rivers, in an average rainfall year, in the present condition (and for present development), of 650 million cubic meters has to occur. If this does not occur, the current situation cannot be sustained and groundwater storage will deplete progressively.

e) The model brings out the extreme sensitivity of the Sabarmati river basin flows to rainfall. The model, under the present development, was run for high and low range rainfall situations from the observed rainfall data. Under these conditions the river flows varied between 4,100 million cubic meters and 780 million cubic meters.

2.7.1 Consumptive Use (ET) of Water

For the present situation, the total consumptive use is 14,796 million cubic meters. It comprises 5,224 million cubic meters (35%) for nature sector, 9,442 million cubic meters (64%) for agriculture sector and 130 million cubic

Table 29
Land Use, Import and Export in Different Scenarios

Sr. No.	Key Attribute	Present	Future-I	Future-II	Future-III	Future-IV	Future-V	Future-VI	Future-VII	Future-VIII
1	Net sown area (Million ha.)	1.234	1.328	1.328	1.328	1.328	1.328	1.328	1.325	1.333
	a) Rainfed area (Million ha.)	0.610	0.334	0.333	0.333	0.502	0.336	0.336	0.438	0.406
	b) Irrigated area (Million ha.)	0.630	0.995	0.995	0.995	0.826	0.992	0.992	0.887	0.927
2	Kharif cropped area (Million ha.) (Rain-fed and Irrigated)	0.851	0.788	0.788	0.926	0.855	1.154	1.154	1.173	0.956
3	Rabi cropped area (Million ha.)	0.291	0.404	0.404	0.440	0.359	0.436	0.436	0.460	0.318
4	Hot weather cropped area (Million ha.)	0.106	0.166	0.166	0.182	0.138	0.190	0.190	0.171	0.051
5	Two seasonal (K+R) (Million ha.)	0.220	0.285	0.285	0.195	0.260	0.054	0.054	0.050	0.207
6	Two seasonal (R+HW) (Million ha.)	0.011	0.0169	0.0169	0.0140	0.0140	NP	NP	NP	0.021
7	Perennials (Million ha.)	0.038	0.060	0.060	0.041	0.049	NP	NP	NP	0.0379
8	Irrigated Kharif (Million ha.)	0.234	0.366	0.366	0.559	0.300	0.830	0.830	0.747	0.552
9	Irrigated Rabi (Million ha.)	0.246	0.389	0.389	0.277	0.327	0.160	0.160	0.138	0.293
10	Irrigated hot weather (Million ha.)	0.097	0.152	0.152	0.168	0.126	0.190	0.190	0.171	0.049
11	Irrigated two seasonal (K+R) (Million ha.)	0.164	0.261	0.261	0.178	0.217	0.042	0.042	0.038	0.152
12	Irrigated two seasonal (R+HW) (Million ha.)	0.011	0.017	0.017	0.014	0.014	NP	NP	NP	0.002
13	Irrigated perennials (Million ha.)	0.038	0.600	0.600	0.401	0.500	NP	NP	NP	0.038
14	Net irrigated area (Million ha.) (Surface water and Groundwater)	0.629	0.995	0.995	0.995	0.826	0.992	0.992	0.887	0.927
15	Gross irrigated area (Million ha.)	0.789	1.244	1.244	1.236	1.032	1.222	1.222	1.094	1.085
16	Groundwater Irrigation (Million ha.)	0.449	0.715	0.715	0.715	0.593	0.712	0.613	0.472	0.653
17	Surface water irrigation (Million ha.)	0.340	0.529	0.529	0.521	0.439	0.510	0.609	0.622	0.432
18	Land under forest (Million ha.)	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410
19	Import (10 ⁶ m ³)	1580	3084	1580	3938	2334	3084	3084	3084	2384
20	Export (10 ⁶ m ³)	260	425	260	1415	425	425	425	425	1024

Note: Import of water shown in Scenario-F-VI includes Narmada water pumped for filling reservoir in sub basin 1 and sub basin 2.

meters (1%) for people sector (D&I). The agricultural use of 9,442 million cubic meters is made up of ET from rainfall and soil moisture in rain-fed lands as well as irrigated lands, additional ET met from irrigation and reservoir evaporation. The consumptive use includes considerable non-beneficial ET for nature sector (1,814 million cubic meters) and for agriculture sector (1,447 million cubic meters). These two together are of the same order as the river flow itself. Thus, reduction of non-beneficial ET through water and soil and water management is essential for improvement in river flows.

The value of ET in the future 'Business-as-Usual' (F-I) scenario is 17,519 million cubic meters. Through the various water saving measures, in F-VII it could be reduced to 14,191 million cubic meters (18%) as in the scenario F-VII.

The Scenario F-VIII has been attempted to get the maximum practicable expansion of irrigated area, without reducing the river flows much below the present level, and that too with limited imports. In this combination, the natural and induced recharge, necessary to maintain the groundwater balance, and the need for pumping of groundwater to canals have been minimized. In this scenario, the total consumptive use is 15,209 million cubic meters. Since this is almost same as the present value of 14,796 million cubic meters, the scenario F-VIII does not require substantially additional water resources, as shown in Table 25 and Figure 12.

The consumptive use of agricultural sector can be further classified by the status of the land (rainfed or irrigated). Part of the consumptive use from irrigated land is met either from rainfall and/or from irrigation waters. Non-beneficial consumptive use would be from reservoirs, waterlogged areas, or from land without crops in particular season (fallow). Figure 13 depicts the Composition of consumptive use in agriculture sector.

2.7.2 Surface Water

Around 1960, in average condition as per the model, the withdrawal of surface water was only 4 percent of the total inputs, and return flow contributed only 2 percent of inputs, while the base flow was available from August to May. This is considered to represent near pristine conditions.

In the present situation with average rainfall, return flows contribute 9 percent of total inputs and withdrawals are equal to 35 percent of the inputs. Thus both of these may lead to risk of pollution of downstream waters.

In the future scenarios (F-I to F-VIII), although further import of Narmada river waters could maintain the withdrawal to input ratio at around the present figure, the return flows would constitute about 12 to 13 percent of total inputs, thus indicating a somewhat larger hazard of pollution of groundwater. However, the base flow availability improves.

The total sustainable river flows (after providing for the natural and induced recharge from river to groundwater) and their monthly distribution is shown in Table 27. The monthly river flows in selected three scenarios are shown in Figure-14. The low flows (November to May) would be particularly affected by the pattern of development.

2.7.3 Groundwater

In Sabarmati basin, extensive groundwater use has been practiced. In the 'present' situation, return flows, natural and 'human induced' together, constitute 54 percent of the inputs. At the same time withdrawals are 112 percent of the input, thus signifying mining of groundwater and unsustainable groundwater balance, which would be made good by further surface to ground water transfers. The situation would improve slightly in future due to large additional Narmada imports. But even then, return flow would continue to constitute about 40 percent of the inputs, indicating risk of pollution. The withdrawals would constitute 66 to 86 percent of the input, thus leaving only small quantity to contribute to the base flow.

The withdrawals for both surface and groundwater for different purposes and for different scenarios are shown in Figure 15. These withdrawals depend not on the net irrigation provided in each scenario, but these are more sensitive to the seasonal distribution of the net irrigated area, because kharif irrigation requires comparatively less water.

2.7.4 Groundwater Pumping and Induced Recharge

The heavy withdrawals from surface and groundwater represent the demands, which are to be fulfilled from the available surface water and groundwater. When the surface water was not available, additional pumping from groundwater to the surface canals was required to meet the demands. But, because of these heavy groundwater withdrawals, the sustainability of the groundwater storage, under the average recharge conditions is disturbed. This required the assumption of natural and induced recharge from surface to ground waters, as has been already discussed.

The scenario-wise position about the need for groundwater pumping into canals for meeting deficits in surface water irrigation and of natural and induced recharge to make ground water position sustainable is given in Table 26. The groundwater pumping to canals is necessary mostly in June and in the low flow months, whereas the natural and induced recharge from river to groundwater occurs mostly during the high flow months.

2.8 Water Situation Indicators

Water stress for a river basin is defined in terms of ratio of average annual water withdrawals for human use (agriculture, D&I and other uses) as a percentage of the total water availability i.e. mean annual run off of the basin. In simple terms it reflects pressure created by water withdrawals on basin water resources. Water stress at a country level can be arrived at by aggregating the withdrawals and comparing it to total renewable water resources of the country. Water stress begins when withdrawals of freshwater rise above 10 percent of renewable resources. Medium to high stress is set to occur when water use exceeds 20 percent of renewable resources. Countries generally experience high water stress when water use exceeds renewable resource by 40% (ADB, 2004). At such levels, their patterns of use may not be sustainable, and water scarcity is likely to become the limiting factor to economic growth.

2.8.1 Water Situation Indicators (WSI)

A survey of indicators of water stress mentioned in International literature was made. The three main types recommended in recent years are:

- (a) The water stress indicator (WSI) used in international literature is one based on Alcamo, et.al, (2002), and is defined as

$$\text{WSI} = \text{Withdrawal} / \text{Mean Annual (natural) Runoff (MAR)}$$

- (b) Smakhtin, et.al, (2002) suggested a modification to account for water use for maintaining ecology and environment

$$\text{WSI} = \text{Withdrawal} / (\text{MAR} - \text{Environmental water requirement for aquatic eco-system})$$

- (c) At the 3rd World Water Forum in March 2003, ICID suggested the following relationship

$$\text{WSI} = \text{Withdrawal} / (\text{MAR} - \text{Society's need for food, people and nature as evidenced by consumptive use})$$

The following indicators have been proposed in this study undertaken under CPSP in Indian basins.

The views of indicators is primarily aimed at abstracting the impact of human use on water availability and extend the outcome of sample basins to recommend policies on the basis of similarities and dissimilarities in the state of overall situation at the basin level. The following four indicators of the “water situation” are being used.

Indicator 1: Withdrawals/ Total input to surface water

Indicator 2: Returns/ total input to surface water

Indicator 3: Withdrawals/ total input to groundwater

Indicator 4: Returns/ total input to groundwater

These indicators have been considered more relevant to Indian situation due to the following reasons.

1. There is a large groundwater use in India. One needs indicators, which reflect water uses from both surface and ground water sources.
2. The WSI as defined based on ‘withdrawals’; out of which a substantial part may return. Either one needs to consider the returns as an additional resource, adding to the natural runoff, or, one needs to consider the ‘net consumptive use’ rather than withdrawals.
3. The change suggested by Smakhtin, et.al presupposes that the environmental water flow requirement for aquatic eco-system has an overriding priority, and only the rest of the water flow is available for any use for terrestrial natural eco-systems, food or people. This does not appear appropriate for many basins that are water-deficit or at a threshold level. The in-stream environmental uses is in terms of flow requirement and is not a consumptive use as in other cases and can instead be considered as one of the requirements, competing with others.
4. The methodology for computing the MAR by considering the withdrawals and returns has not been explained by Alcamo and Smakhtin. Since large land use changes can also affect the natural supply, this becomes more complex. Either a ‘natural’ land use, which does not allow for human interventions through agriculture, or a ‘pseudo-natural’ condition, where agriculture is allowed but irrigation is not, would have to be defined for this purpose. In case of Sabarmati basin, “past” conditions may correspond to a ‘pseudo-natural’ condition.

Instead of basing the indicator on gross withdrawals (numerator) and gross inputs (including human induced returns), these could also have been based on the net consumption (numerator) and the natural inputs (under the pseudo-natural conditions, without human interventions other than land use modification in the denominator).

The proposed indicators have been used to depict the water situation in Sabarmati basin in quantitative as well as qualitative terms. Indicators 1 and 3 depict the level of withdrawals as fractions of total water available in surface and groundwater system respectively, while indicators 2 and 4 depict the potential hazards to water quality in surface and ground water systems respectively.

The indicators were sub divided into 3 to 4 classes each to represent the degree of water stress as given in box1:

2.8.2 Water Situation Indicators of Sabarmati River Basin

The water related status of the Sabarmati basin, under the past, present and alternate future scenarios was studied under the average precipitation conditions. These studies used artificial recharge of river waters into the groundwater to obtain a stable ground water regime.

The values of the water situation indicators (WSIs) for the different conditions, as resulting from these studies, are given in Table 30.

2.9 Major Findings of the Assessment

- o Non-beneficial ET in the nature and agriculture sectors is of the same order as the quantum of annual river flow. It therefore, follows that reduction of non-beneficial ET through rainwater harvesting, soil and water management would be a potential strategy for reducing consumptive use.
- o Import of Narmada water is necessary not only to sustain the present level of withdrawals but also to meet the increased future needs, including that for improvement of low flows.
- o Present groundwater use is unsustainable. While the situation would improve slightly in future due to large additional Narmada imports, composition of return flow indicates much higher risk of groundwater pollution.
- o Scope for changes in cropping pattern towards growing crops requiring less water and higher commercial value and adoption of efficient methods of irrigation and water management hold promise to mitigate the severe water stress conditions.
- o The shortage of surface water and over use of groundwater in the basin would require additional imports in future from Narmada despite using soil and water conservation and other water saving measures such as improving surface water

Box 1

Categories of surface and groundwater indicators

(a) Indicator 1 - Surface water withdrawals	(c) Indicator 3 -Groundwater withdrawals
1. Very high stress – value of indicator more than 0.8	1. Very high stress – value of indicator more than 0.8
2. High stress – value of indicator between 0.4 and 0.8	2. High stress – value of indicator between 0.4 and 0.8
3. Moderate stress – value of indicator between 0.2 and 0.4	3. Moderate stress – value of indicator between 0.2 and 0.4
4. Low stress – value of indicator less than 0.2	4. Low stress value of indicator less than 0.2
(b) Indicator 2 - Surface water quality	(d) Indicator 4 -Groundwater quality
1. Very high threat – value of indicator more than 0.8	1. Very high threat – value of indicator more than 0.8
2. High threat value – value of indicator between 0.2 to 0.8	2. High threat - value of indicator between 0.4 and 0.8
3. Moderate threat - value of indicator between 0.05 and 0.2	3. Moderate threat – value of indicator between 0.2 and 0.4
4. Low or no threat – value of indicator less than 0.05	4. Low threat – value of indicator less than 0.2

Table 30
Water Situation Indicators for all the Sectors

Component	Past (1960)	Present (1995)	F-I	F-II	F-III	F-IV	F-V	F-VI	F-VII	F-VIII
Indicator 1	0.05	0.28	0.34	0.42	0.25	0.34	0.25	0.28	0.30	0.23
Indicator 2	0.02	0.10	0.18	0.24	0.16	0.20	0.16	0.17	0.16	0.17
Indicator 3	0.30	0.98	0.93	0.98	0.95	0.97	0.96	1.00	0.91	0.95
Indicator 4	0.14	0.50	0.42	0.43	0.41	0.42	0.42	0.44	0.45	0.42

As the value of indicator 1 is less than 0.4 under 'Present' and Future V, VI, VII and VIII Scenarios, the Sabarmati river basin is moderately stressed through surface water withdrawal.

The value of indicator 2 is less than 0.2 in all the scenarios except Future II, the basin can be categorized as moderately stressed in the surface water quality.

The value of indicator 3 is more than 0.8 except past scenarios, the basin can be categorized as highly stressed in respect of groundwater withdrawals.

The value of indicator 4 is lying between 0.4 to 0.8 in all the scenarios, except past. Hence this basin can be categorized as high threat on account of groundwater quality.

distribution, curtailing wasteful consumptive use, introduction of sprinkler and micro irrigation, etc.

- o As far as pollution of surface water, preliminary consultations at Ahmedabad brought out the need for treating all municipal and industrial waste before

discharging it to the main river or its tributaries. Local wastewater can be treated and used for gardening/lawn purposes. Treated bulk wastewater treated by large industries or through common treatment plants can be disposed off for agricultural use.

CHAPTER 3

POLICY RELATED ISSUES EMERGING FROM THE STUDY**3.0 General**

The comprehensive assessment made through application of BHIWA model for past, present and future conditions gives a sound and much broader Knowledge Base to understand the state of water availability under alternative scenarios by different use sectors at the basin/sub basin level, source wise (surface and groundwater) and at the aggregate basin level. In particular, the scenario-based approach has allowed the testing of various plausible policy options for managing water and related land resources. While food sufficiency at the basin level and benefits of expanding irrigation to improve rural livelihood requires setting of targets through socio-economic models and at country/global level, model such as BHIWA when applied to individual basin can consider constraints of 'within basin' availability of water and land, and help in assessing in-basin water storages, artificial recharge to groundwater and interbasin surface water transfers. The limited use of BHIWA to the water deficit Sabarmati basin has brought out important policy options that have application to similarly placed river basins and, through these to national water issues. The specific and overall conclusions relating to issues of three water use sectors emerging from Sabarmati study in the context of IWRDM and sustainable water use are described in the following paragraphs.

3.1 Shift in the Concept of Water Resources

The nature sector water use needs to be accounted carefully as it affects water availability in the rivers and aquifers and is important for maintaining terrestrial as well as aquatic ecology. Similarly, harvesting of rainfall and local run off, over use of groundwater, etc. has large impact on availability of river waters. These considerations require that precipitation which is the primary source of all waters

on land, rather than the terrestrial run off (surface and groundwater) is to be considered as the *primary renewable water resource*.

3.2 Accounting Water Use by Sectors and their Integration

- The consumptive uses of individual sectors (water for agriculture, people and nature) need to be assessed and integrated in order to understand the real impacts of land and water use and management policies. It is the consumptive use, which causes the depletion of the resource/water availability. Assessment of consumptive uses requires data on water withdrawals, for irrigation, domestic and industrial and other uses. Such data are found to be inadequate and have been assessed indirectly using crop areas and irrigation statistics, supply norms etc. Similarly, data on efficiency in water use and returns are lacking in most cases. For better assessment of withdrawals and consumptive use and consequently state of water availability, it is necessary to improve the water related database.

Integration of sectoral water uses is made possible through application of model such as BHIWA and can help in taking a holistic view at the water needs and their impacts on the water availability.

- Maintenance of water accounts, in terms of withdrawals, consumption and returns, separately for the requirements of the food, the people and the nature sector leads to a better understanding of the water uses. For example, when the consumption of the rainwater by the terrestrial ecosystem is considered, the nature sector requirements become significant.

- A study of the balanced hydrologic cycle, which allow the study of the separate and combined water balances of the different components is an important accounting tool for integration of the different parts of the cycle.

3.3 Accounting Return Flows

- The return flows from both point and non-point sources constitute a sizeable water resource.
- They could be of different qualities, depending on the water management by each use sector.
- The return flows out of the withdrawals from surface and ground water are available for reuse, subject to proper treatment for ensuring water quality standard, as required. A proper assessment of water resources of a basin in due consideration to return flow is an exercise for future.

3.4 Consumptive Use Management

- The consumptive use management is to be treated as an integral part of water and land related resources management. In particular, the consumptive use could be reduced in nature sector by proper weed control, limiting the root zone depths and soil moisture holding capacities, for patchy barren lands, which seem to evaporate water withdrawal benefit to either the natural ecologies or to the food and the people sector.
- In the agriculture sector, reduction of non-beneficial consumptive use is possible through mulching (including use of plastic sheets), creation of moist micro-climates, and use of micro irrigation etc. Increase in beneficial consumptive use is possible through conversion of wastelands or through watershed management and water resource development.
- The additional consumptive use requirements, over and above the effective rainfall, in irrigated crop are much lesser in the wet season as compared to the post or pre-monsoon seasons. A seasonal shift in the cropping patterns can achieve a considerable saving in the consumptive use.

3.5 Integrating Surface Water and Groundwater Use in Irrigation in a Conjunctive Manner

- A need for conjunctive use of surface and ground waters exists in surface water irrigated commands. About 75% of the current irrigation in the Sabarmati

basin is through groundwater. The groundwater withdrawals are much larger than irrigated induced recharge. Water imports and artificial recharge are some of the options available to enhance the recharge of groundwater.

3.6 Integrated Management of Land and Water Resources

- Appropriate choice of a cropping pattern with water requirements matching the availability of water and types of soil, is important. As already stated, in situation of low rainfall, a shift towards kharif irrigation is beneficial.
- Training/capacity building for proper land and water management and societal interventions is required.

3.7 Option for Interbasin Transfer

- A large inter-basin surface water transfer is an obvious option to meet the water needs of the basin for agriculture and allowing restoration of groundwater regime, as also for providing environmental flows required for riverine eco-system, besides improving river water quality through reuse of effluents from D&I for irrigation.
- To provide livelihood to the rural population, productive and remunerative agriculture is a pre-requisite for generating local income and prevent migration. In the comparatively dry basins having a considerable rural population, rain-fed agriculture may not generate enough local incomes. To alleviate poverty and to sustain livelihoods, interbasin transfer would provide an attractive option.

3.8 Preventing Pollution of Natural Waters

- The very high proportion of return flows, to the total inputs, both in the surface and groundwater subsystems, in basins like Sabarmati, increases the water quality hazards in a very large way.
- Adequate safeguards in terms of treatment, should be taken regarding the quality of wastewater (domestic and industry) being discharged in the natural water. Reuse of the wastewaters, after some treatment, for other uses, without discharging these in the natural waters, appears to be a better strategy.

3.9 Watershed Development

- Though watershed development/management enables more equitable use of land and water and

often involves harvesting of the rain water at the place of its occurrence, as many reservoirs like Dharoi, Hathmati etc. in the Sabarmati basin did not fill up even up to half of their capacity in several years since their construction, watershed development upstream has to be discouraged to cause no further reduction in the water availability (if one desires to consolidate the existing systems).

3.10 Water for People - Dimensions of Priority

- A high priority for domestic water needs to be integrated as the priority in allocation when the resource is limited, priority in quality where alternate sources have different quality, and priority in regard to dependability
- National Water Policy accords first priority for drinking water. The core water demands for drinking, cooking and essential personal hygiene are to be given highest priority as compared to other non-core municipal demands. These non-core demands may have to compete with other non-municipal demands.
- With rapid urbanisation, the traditional sources of water are getting exhausted and polluted,

necessitating need for exploitation of distant resources which becomes expensive and under such a situation, Inter basin water transfer should be considered as one of the options.

3.11 Water for Nature – Environmental Flow Requirements (EFR)

- Water requirements of the nature sector need to include both the requirements (mostly consumptive) of the terrestrial ecosystems like forests, grasslands, wetlands, etc. as also the water requirements (mostly non-consumptive) of the aquatic ecosystems. Both of these have to be decided through demand estimation, management, and tradeoffs.
- Stipulation of a desirable environment flow requirement for riverine eco-system in water deficit basins needs more investigation and proper substantiation. However, the EFRs need to be recognised as a valid requirement. Their estimation methods could be ad hoc and hydrology based, initially. Better methods based on water regimes required by different species as also based on the trade offs between environmental flow and uses, as preferred by the society, need to be evolved.

ANNEXURES

ANNEXURE 1

BRIEF DESCRIPTION OF BHIWA MODEL

The Basin-wide Holistic Integrated Water Management (BHIWA) model as evolved for CPSP has 9 computation modules. The model is developed in Microsoft EXCEL software and has a number of spreadsheets. The model works, initially, in the calibration mode using the observed data. After obtaining a generally satisfactory calibration, it is used as a tool for assessing the possible status of the water resources of the basin, under different scenarios in the simulation mode. This process is depicted in Figure A1. For using the model, a river basin is first to be divided into hydrologically homogeneous sub-basins and each sub-basin into a number of land parcels each depicting a particular category/sub-category of land use. The model accommodates a maximum of 5 sub-basins and each sub-basin can be divided into a maximum of 25 land parcel types. The hydrologic computations are first performed for each land parcel in terms of water depth in millimeter over the area and then aggregated in volume units (million cubic meters) at the sub-basin level.

Natural (Hydrologic) Module 1: Computation of actual ET, quick runoff and natural recharge

The model calculates water balances for the upper and lower zones viz. soil profile and groundwater system for each land parcel, given soil moisture holding capacity of the parcel, and area averages of rainfall, and reference evapo-transpiration for the sub-basin. The soil profile component of the model partitions the rainfall into actual evapo-transpiration (ET) and excess water. The actual ET (AET) is calculated as a function of potential ET and the actual moisture availability, as proportion of the root-zone soil moisture capacity for each land use type. These

functional relations depict how the actual ET reduces with reduction of soil moisture availability, or indirectly the tension in the root zone. The excess water is further divided into deep percolation (natural recharge to groundwater) and quick runoff from land areas to the river. The quick runoff from all land parcels is aggregated into a single entity to represent natural contribution from rainfall to the river system. Likewise, natural recharge to groundwater under various land categories is lumped into a single groundwater entity representing the natural contribution of rainfall to the groundwater.

Module 2: Computation of irrigation withdrawal

This module calculates the requirement of additional water for each of the irrigated land parcels using data from previous module on shortfalls to meet the Potential Evapo-transpiration (PET) requirements. Net and gross irrigation requirements are computed source-wise using data on irrigation system efficiencies and proportion of surface water irrigation. For parcels having paddy crop, net water requirements are calculated taking into account user prescribed monthly percolation. Estimates of withdrawals for irrigation are arrived at finally considering “deficit irrigation” specified if any.

Module 3: Computation of irrigation returns

These are computed separately for surface water and groundwater irrigation systems using user specified information on potential return from the total water withdrawn, in excess of the AET and that part of the wasteful return, that will be lost as ET from swamps/waterlogged areas within cropped lands. The difference between the potential and the wasteful return is further divided into the components returning to surface and groundwater system.

Module 4: Accounting for Evapo-transpiration (ET) by sector

This module is designed for accounting ET by different use sectors. This is achieved through sectoral identification of each land parcel type. Agriculture land parcels are further divided into rain-fed and irrigated parcels. Parcel ET is designated as beneficial, if it is productive from consideration of sectoral water use. Otherwise it is classified as non-beneficial.

Module 5: Computation of domestic and industrial withdrawals, use and returns

In calibration mode, this module is run on directly fed data. However, in simulation mode, domestic and industrial (D&I) module is used first to project population and water requirements in the targeted “future” year from the user given information on base year, intermediate blocks, population growth rates and proportion of urban population to total population. Withdrawals are next computed in the model using rural and urban water supply norms and source-wise proportion of supplies. Information on consumptive use fraction and returns is used to calculate the total return as well as its components to surface and groundwater systems.

Module 6: Computation of the river water balance

It aggregates all inputs to the river including quick run off, base flow and returns from irrigation, D&I withdrawals and computes balance flow taking into account given values of storage changes and requirements of environmental flow. Provision exists to account for adjustments in surface water withdrawals through assumption of induced recharge from the river flow to groundwater in cases where the estimated groundwater withdrawal is found to be unsustainable. This module

also has a provision to ensure that the river flow in any month is not less than the specified environmental flow requirement (EFR), or zero, if no EFR is specified. This is achieved through extra pumping from groundwater reservoir to take part of the demands on surface water.

Module 7 to 9: Computation of groundwater balance

The input part of the module facilitates aggregation of input from deep percolation from natural rainfall, return from irrigation and D&I withdrawals and as well as induced recharge if any required from the river. The output components of groundwater system include base flow to river and withdrawals through pumping from ground water reservoir as also pumping into canals to meet the surface water shortages, if there be any. In the simulation mode, the module is designed to achieve a stable groundwater regime under average conditions by adjusting the initial groundwater reservoir storage. Where the total annual input to groundwater is detected to be less than the estimated withdrawals including natural out flow (base flow) to the river, there exists a provision to *manually* balance groundwater through artificial recharge from surplus river flows for achieving a sustainable or balanced groundwater regime. Consequences of modifications in groundwater reservoir system are carried forward to modify the river water balance.

In addition to the above modules, there are worksheets to facilitate data inputs, and generation of aggregated results in the form of tables and charts.

The model runs on a monthly time step simulating average hydrological year. In the calibration mode, however, a model can be applied either to a single year (good, average or dry) or to a sequence of years (maximum length 5 years).

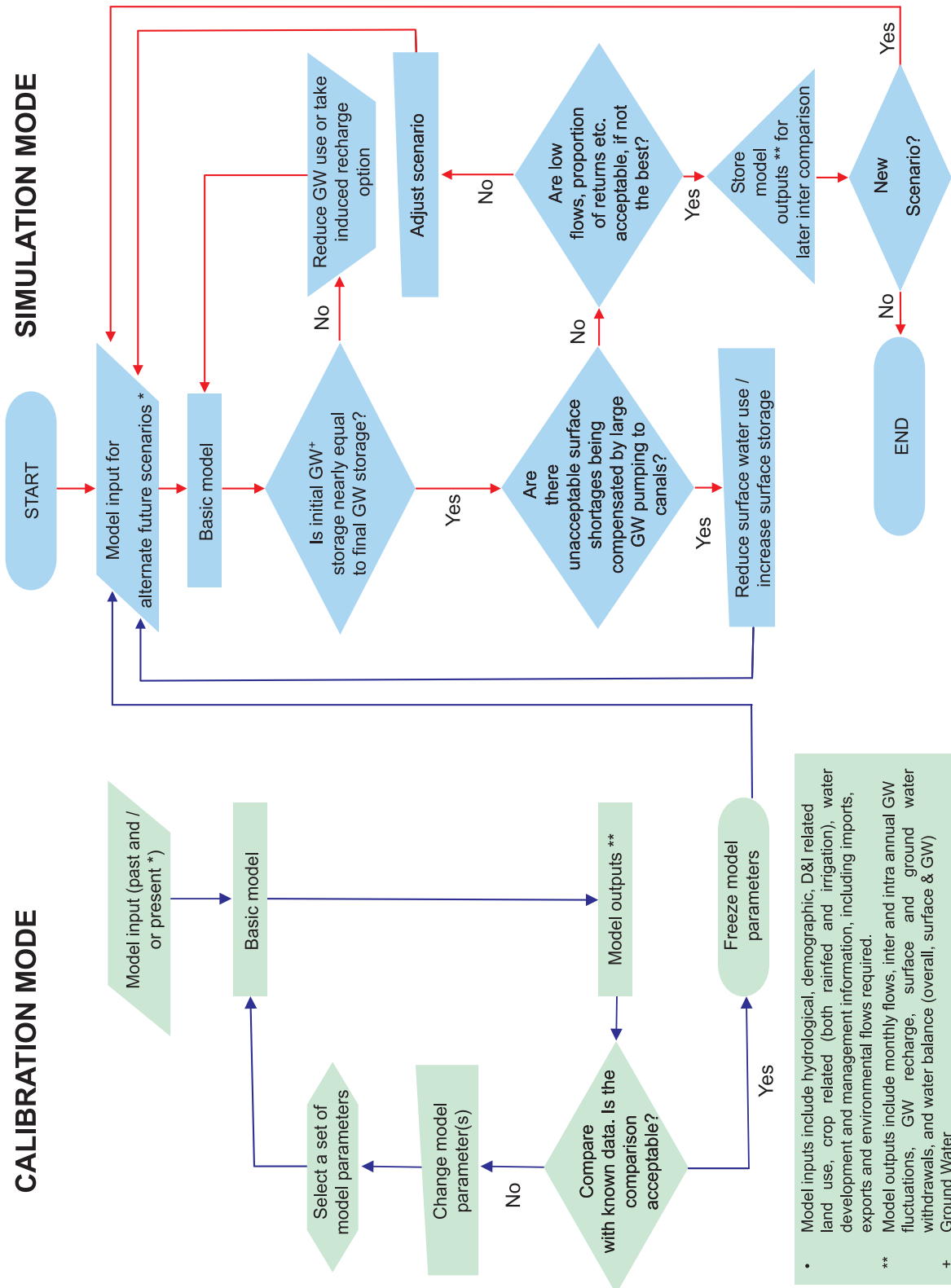


Figure A1 Logical Sequence of BHIWA Model

ANNEXURE 2

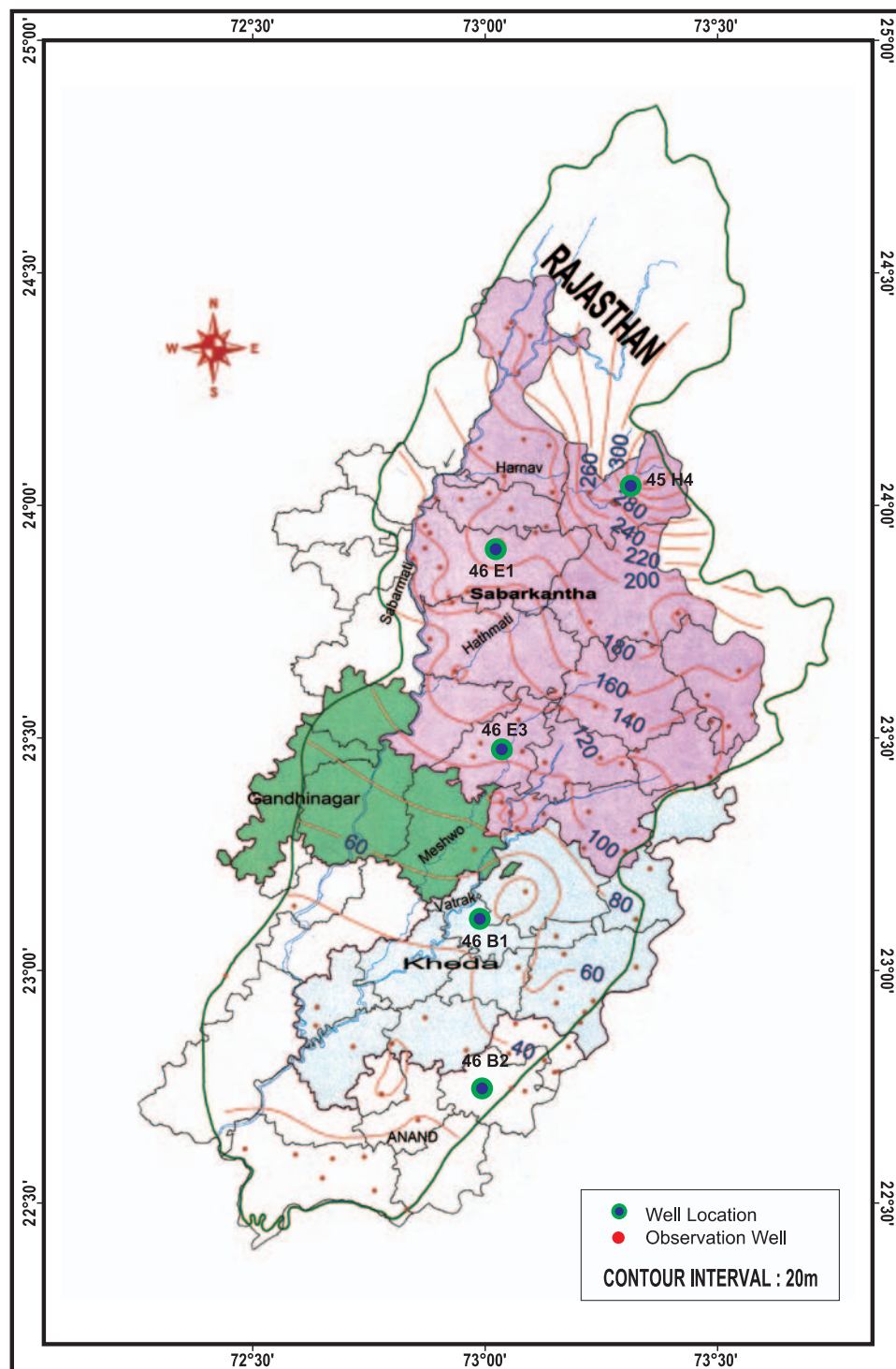


Figure A2 Map Showing Reduced Water Level Contours of Unconfined Aquifers (1991)

ANNEXURE 2 (CONTD...)

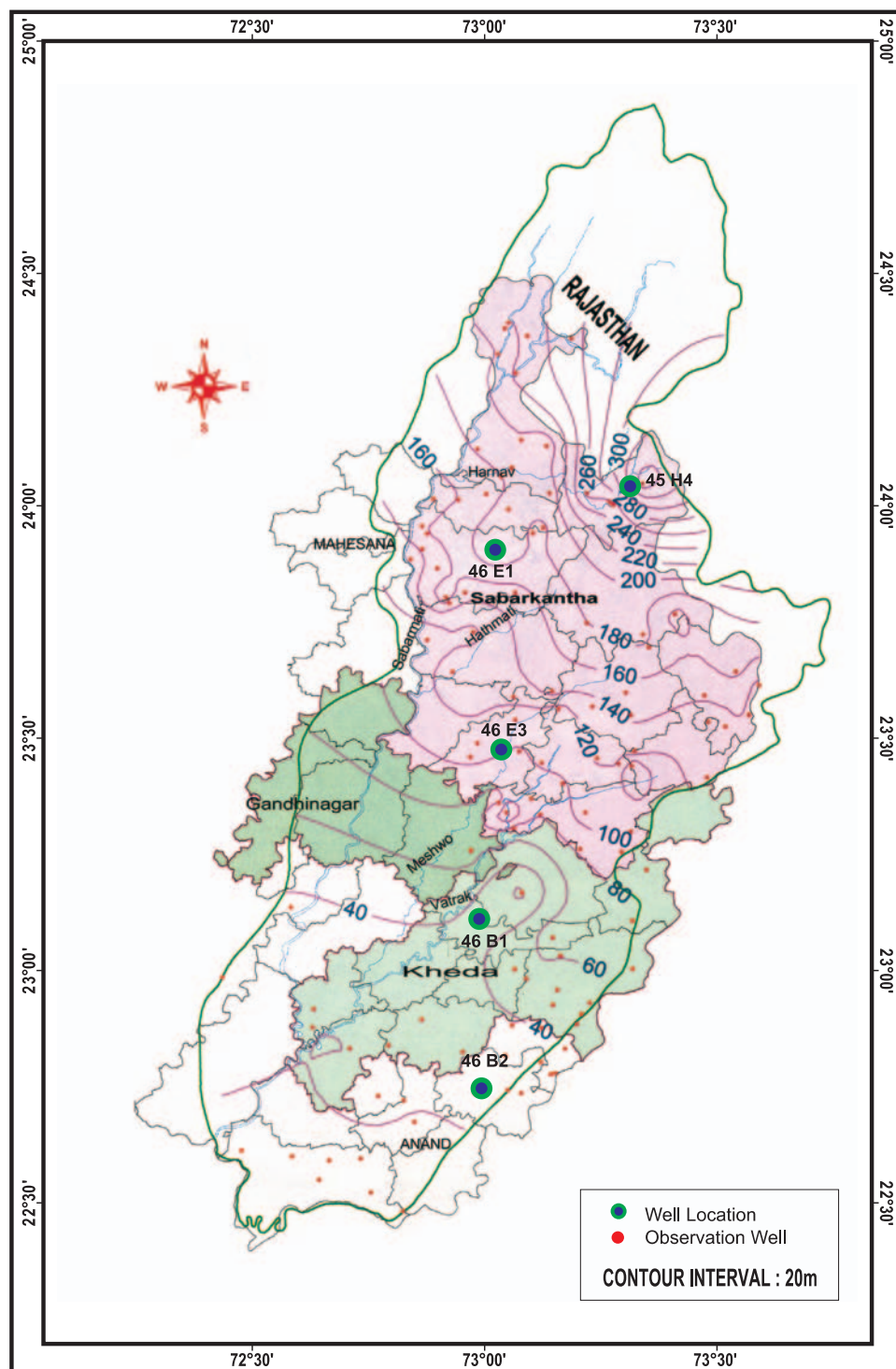


Figure A3 Map Showing Reduced Water Level Contours of Unconfined Aquifers (2001)

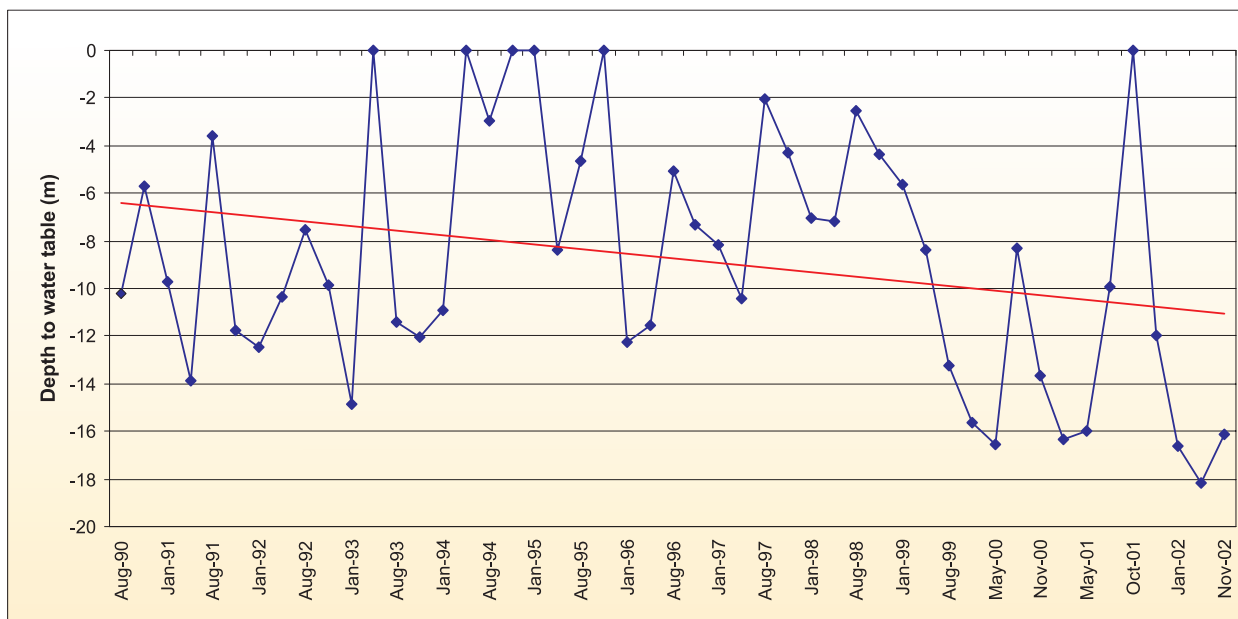


Figure A4 Groundwater Table Fluctuations in Sabarmati Basin (August 1990 to November 2002)
(Well No. 46E3A02A, Latitude: 23°22'40", Longitude: 73°01'00")

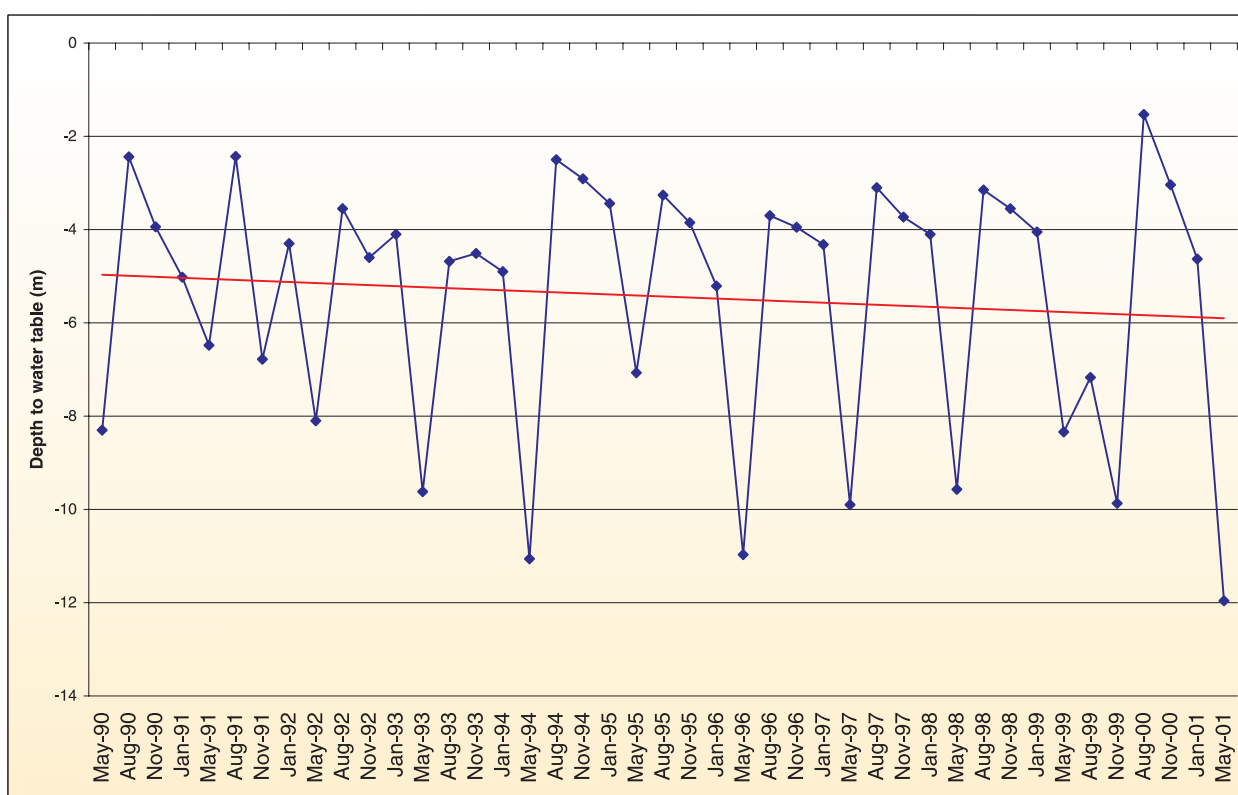


Figure A5 Groundwater Table Fluctuations in Sabarmati Basin (May 1990 to May 2001)
(Well No. 45H4B01, Latitude: 24°00'30", Longitude: 73°21'15")

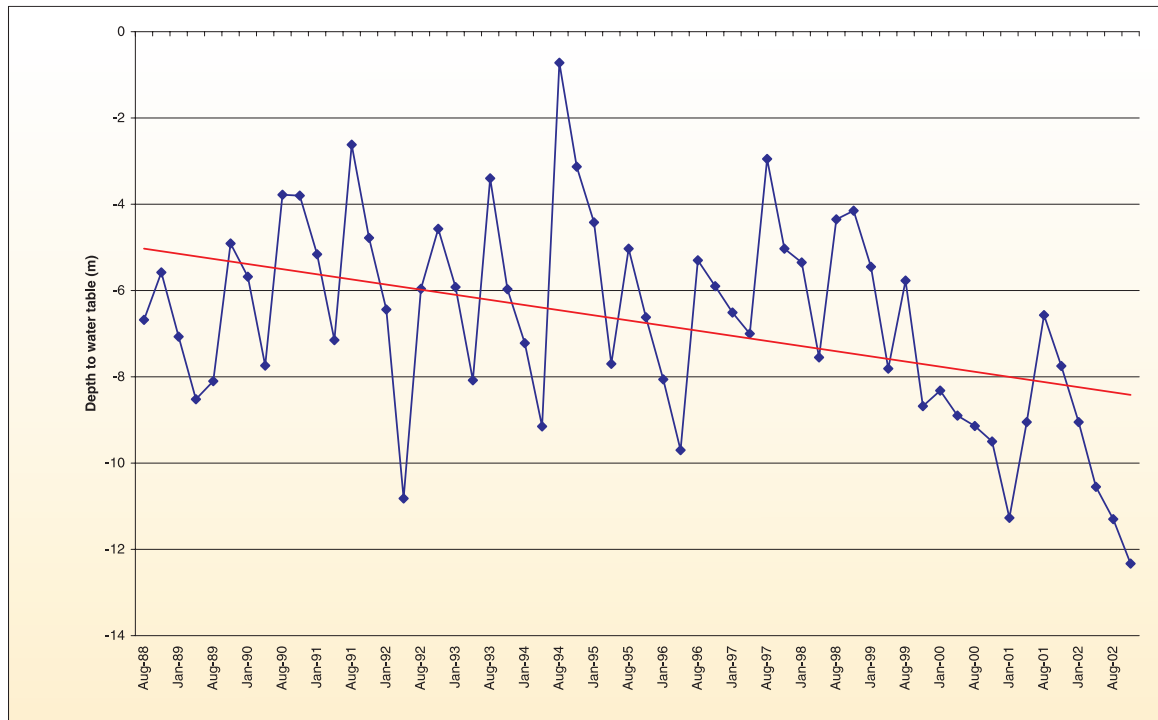


Figure A6 Groundwater Table Fluctuations in Sabarmati Basin (August 1988 to November 2002)
(Well No. 46E1A02, Latitude: 23°50'30", Longitude: 73°12'30")

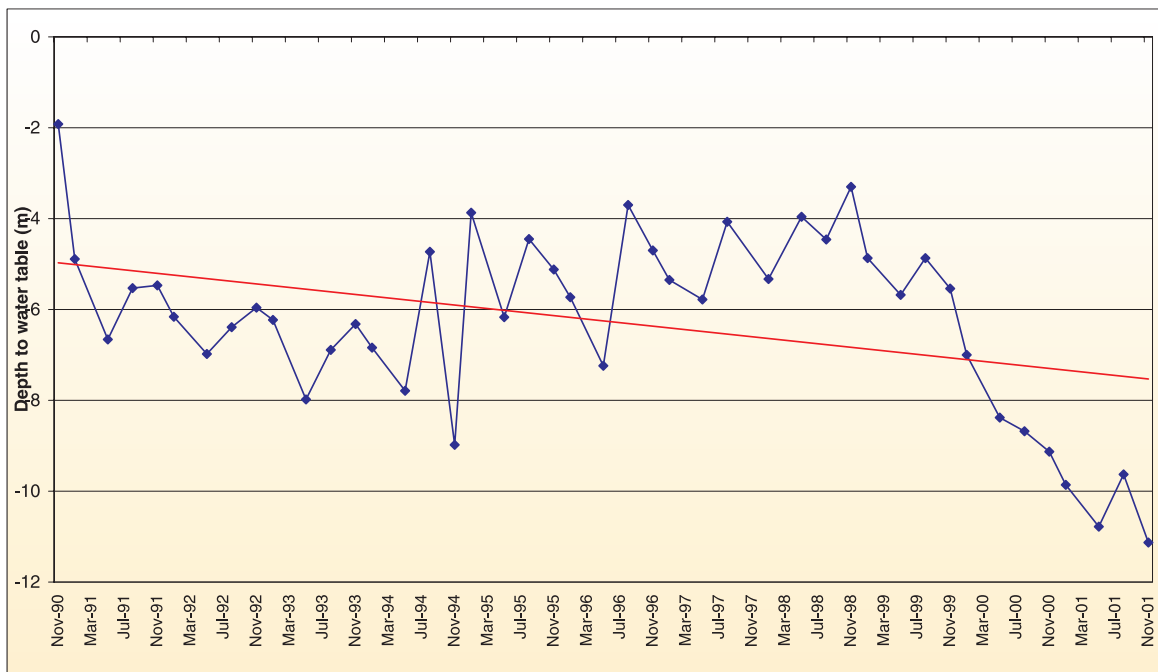


Figure A7 Groundwater Table Fluctuations in Sabarmati Basin (November 1990 to November 2001)
(Well No. 46B2D03, Latitude: 22°34'30", Longitude: 72°58'20")

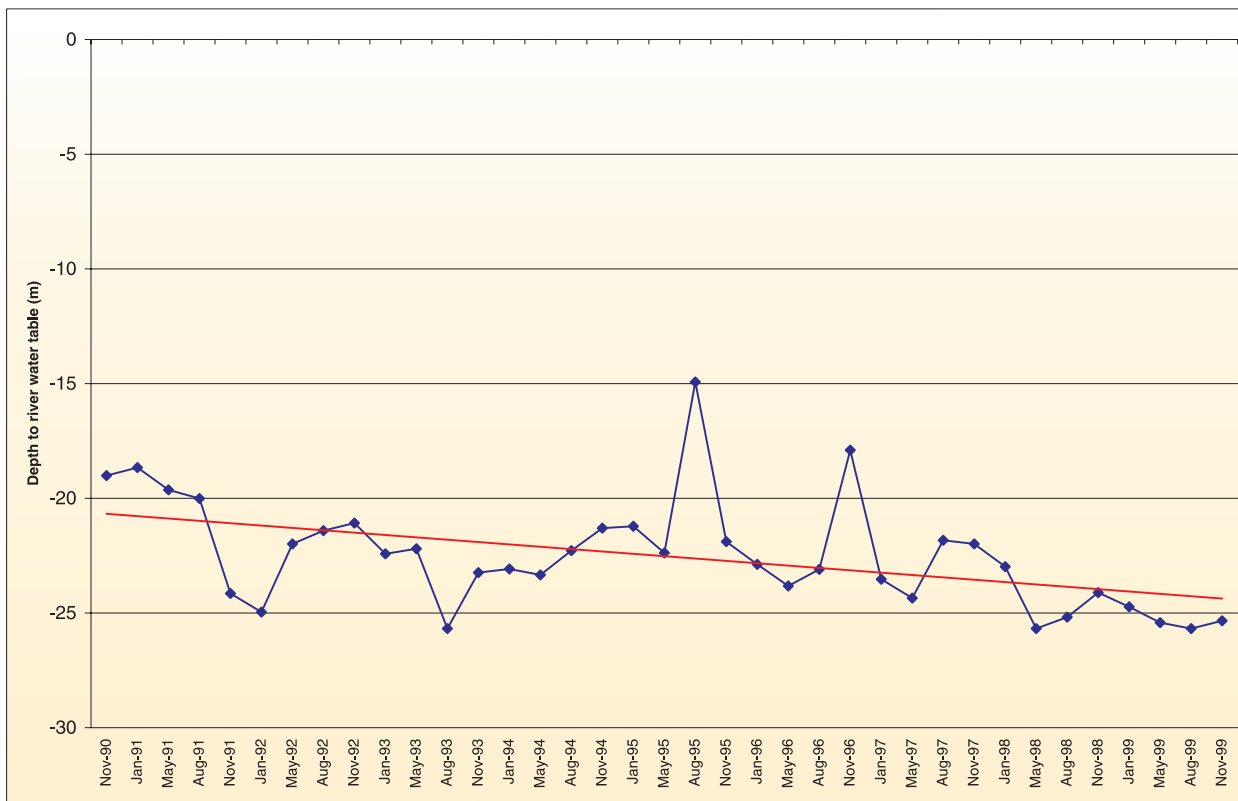


Figure A8 Groundwater Table Fluctuations in Sabarmati Basin (May 1989 to November 1999)
(Well No. 46B1D02, Latitude: 22°58'30", Longitude: 72°53'45")

ANNEXURE 3
EXISTING MAJOR AND MEDIUM IRRIGATION PROJECTS IN SABARMATI
RIVER BASIN
(GUJARAT PORTION ONLY)

Name of Reservoir / Diversion scheme	River / Tributary	Dead storage (10 ⁶ m ³)	Live storage (10 ⁶ m ³)	Designed Irrigation potential area (ha)
Major and Medium projects				
Dharoi Dam	Sabarmati	89.91	775.89	66,796
Watrak Dam	Watrak	8.490	134.25	16,894
Mazam Dam	Mazam	3.37	34.76	5,259
Harnav Dam*	Harnav	1.70	19.97	3,440
Wasna Barrage (Fatewadi Canal system)	Sabarmati	—	—	33,600
Hathmati Dam**	Hathmati	3.51	149.02	27,492
Indrasi Dam **	Hathmati	0.39	18.80	—
Guhai dam	Guhai	5.3	57.04	5,831
Raipur Weir*** (Kharicut Canal System)	Khari	—	—	10,300
Meshwa Dam	Meshwa	4.87	77.20	17,204
Raska Weir	Meshwa	—	—	10,320
Waidy	Waidy	1.33	12.27	1,336

* - Includes Harnav Weirs; ** - includes Hathmati Weirs; *** - includes Karol and Limla

ANNEXURE 4
TALUKA-WISE INDUSTRIAL WATER DEMAND IN SABARMATI BASIN (M³/YEAR)
(GUJARAT PORTION ONLY)

Taluka	Industrial requirement
Ahmedabad	2,79,94,500 ¹
Anand	5,46,400
Daskroi	27,400
Danta	1,13,500
Dehgam	2,63,900
Dholka	6,70,200 ²
Gandhinagar	3,88,56,600 ³
Himatnagar	7,29,900 ⁴
Idar	10,300 ⁵
Kadi	2,88,400
Kalol	2,10,40,500 ⁶
Mahemdabad	3,39,500
Mansaa	37,200
Matar	4,82,500
Mehsana	13,54,200
Modasa	8,700
Nadiad	35,72,000 ⁷
Petlad	2,900
Prantil	7,15,000
Sanand	12,18,700
Vijapur	1,28,100
Viramnagar	3,65,000
Other Miscellaneous	8,76,700
Total	9,96,42,400 (99.64 million m ³)

Source: Indo-French Cooperation Project, Final Report, Vol.1, P.148

- 1 Including 28,35,000 m³ for industrial water requirement in GIDC estates and 1,99,82,500 m³ for IFFCO, AEC, GEB water requirement.
- 2 Including 1,94,200 m³ for industrial water requirement in GIDC estates.
- 3 Including 6,50,000 m³ for industrial water requirement in GIDC estates and 3,79,00,000 m³ for IFFCO,AEC,GEB water requirement.
- 4 Including 72,900 m³ for industrial water requirement in GIDC estates.
- 5 Including 6,600 m³ for industrial water requirement in GIDC estates.
- 6 Including 72,70,500 m³ for IFFCO,AEC,GEB water requirement.
- 7 Including 1,15,300 m³ for industrial water requirement in GIDC estates.

ANNEXURE 5

SUB-BASIN WISE MONTHLY RAINFALL DATA FOR THE YEARS 1995 TO 1999 (mm)

SUB BASIN 1

Month	1995-96	1996-97	1997-98	1998-99	1999-2000	5-year average	Long term average
June	14	72	425	80	124	143	31
July	265	234	195	211	142	209	267
August	71	143	161	113	12	100	317
September	50	90	81	270	38	106	128
October	2	0	1	14	2	4	2
November	0	0	0	0	0	0	2
December	0	0	0	0	0	0	1
January	0	0	0	0	0	0	1
February	0	0	0	0	0	0	1
March	0	0	0	0	0	0	1
April	0	0	0	0	0	0	1
May	0	0	0	0	0	0	2
Total	401	540	863	689	318	562	753

SUB BASIN 2

Month	1995-96	1996-97	1997-98	1998-99	1999-2000	5-year average	Long term average
June	10	72	516	72	147	163	55
July	344	337	546	357	194	358	272
August	113	232	295	186	20	170	356
September	56	93	64	372	49	127	116
October	0	0	0	0	0	0	7
November	0	0	0	0	0	0	3
December	0	0	0	0	0	0	2
January	0	0	0	0	0	0	1
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	1
April	0	0	0	0	0	0	0
May	0	0	0	0	0	0	1
Total	522	735	1421	987	410	819	815

ANNEXURE 5 (CONTD...)

SUB BASIN 3

Month	1995-96	1996-97	1997-98	1998-99	1999-2000	5-year average	Long term average
June	9	109	442	141	143	168	65
July	305	290	248	246	246	267	259
August	106	198	298	184	24	162	294
September	65	129	63	187	22	93	86
October	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0
Total	485	726	1051	759	435	691	704

ANNEXURE 6

SUB-BASIN WISE MONTHLY RAINFALL FOR GOOD, AVERAGE AND BAD YEARS

Month	SB1			SB2			SB3		
	Good	Ave.	Bad	Good	Ave.	Bad	Good	Ave.	Bad
June	69	31	25	94	55	29	152	65	71
July	279	267	223	385	272	256	408	259	187
August	266	317	134	271	356	135	245	294	195
September	88	128	166	131	116	93	129	86	102
October	104	2	0	104	7	0	45	0	0
November	0	2	0	0	3	0	0	0	0
December	0	1	0	0	2	0	0	0	0
January	0	1	0	0	1	0	0	0	0
February	0	1	0	0	0	0	0	0	0
March	0	1	0	0	1	0	0	0	0
April	0	0	0	0	0	0	0	0	0
May	0	2	0	0	1	0	0	0	0
Total	806	753	549	985	815	512	979	704	555

ANNEXURE 7

SUB-BASIN WISE MONTHLY EVAPO-TRANSPIRATION (ET_o) (mm)

Month	SB1	SB2	SB3
June	231	220	220
July	141	145	150
August	124	134	135
September	138	144	150
October	154	163	170
November	111	121	125
December	95	101	100
January	108	116	120
February	120	124	125
March	183	196	200
April	195	208	210
May	244	249	250
Total	1844	1921	1955

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EXPLANATORY NOTES / GLOSSARY

Aquatic: Growing in, living in, or frequenting water.

Aquifer: A porous geological formation, which can store an appreciable amount of groundwater and from which water can be extracted in useful quantities.

Arid: An area or climate that lacks sufficient moisture for agriculture without irrigation. According to Thornthwaite, areas having moisture index below (-) 40 Thornthwaite moisture index.

Base flow: Stream flow coming from ground – water seepage into a stream.

Basin: Area drained by a river including its tributaries upto its common terminus.

Beneficial/Non-beneficial Evapo-transpiration: The evaporation, which provides goods and services to mainland through food production, or through support to ecosystems is considered beneficial. Where no significant goods and services are obtained as through evaporation from soils or from patchy barren lands, which may have few weeds etc., are, considered as non-beneficial.

Consumptive use: That part of water withdrawn that is evaporated, transpired by plants, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

Crop water requirement: The total water needed for evapo-transpiration, land preparation in the case of paddy and other requirements (leaching etc.) from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield.

Discharge site, Gauging site: A selected site on a stream for making observation of velocity and area of cross section

with a view to determining the discharge.

Domestic water use: Water used for household purposes, such as drinking, food preparation, bathing, washing clothes, dishes, dogs, flushing toilets, and watering lawns and gardens.

Drainage area, Catchment area, Catchment, Watershed: The area from which a lake, stream or waterway and reservoir receives surface flow which originates as precipitation. Also called 'watershed' in American usage.

Drainage: The natural or artificial removal of excess surface and ground water from any area into streams and rivers or outlets.

Ecology: The study of the relationships of living things to one another and to their environment.

Effluent—water that flows from a sewage treatment plant after it has been treated.

Environmental Flow Requirement: Water needed for maintaining aquatic and terrestrial systems in a good health.

Estuary: A passage where the tide meets a river current; especially an arm of the sea at the lower end of a river; a 'firth'.

Evaporation—the process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snowfields, but not from leaf surfaces.

Evapotranspiration, or Consumptive use of water: The quantity of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from the soil or from intercepted precipitation on the area in any specified time. It is expressed in water-depth units or depth-area units per unit area.

Fallow land: Land which (during the relevant period) has no crops

Groundwater: The water that occurs in the zone of saturation, from which wells and springs or open channels area fed. This term is sometimes used to also include the suspended water and as loosely synonymous with subsurface water, underground water or subterranean water.

Groundwater balance, or Groundwater budget: A systematic review of inflow, outflow and storage as supplied to the computation or groundwater changes.

Groundwater recharge: Replenishment of groundwater supplies in the zone of saturation, or addition of water to the groundwater storage by natural processes or artificial methods for subsequent withdrawal for beneficial use or to check salt-water intrusion in coastal areas. 2- Also the process of replenishment or addition, of the quantity of such water.

Groundwater table: Upper boundary of groundwater where water pressure is equal to atmosphere, i.e. depth of water level in a borehole when ground water can freely enter the borehole.

Groundwater recession co-efficient: The constant of proportionately which, when multiplied by the groundwater storage (above the 'no base flow' datum) indicates the outflow from the groundwater. In BHIWA Model the groundwater storage is assumed to be a 'linear reservoir'. The recession co-efficient will have a dimension of T^{-1} .

Hot weather: Crop season from February to May

Hydrologic Cycle: The circulation of water from the sea, through the atmosphere, to the land, and thence, often with many delays, back to the sea or ocean through various stages and processes as precipitation, interception, runoff, infiltration, percolation, groundwater storage, evaporation and transpiration, also the many short circuits of the water that is returned to the atmosphere without reaching the sea.

Hydrological models: A simplified representation of a hydrological system leading to an acceptable simulation of the physical and other processes in hydrology.

Index for actual ET estimation: An index to slightly modify the decay of soil moisture through evaporation.

Industrial waste: Any solid, semi-solid or liquid waste generated by a manufacturing or processing plant.

Industrial water use: Water used for industrial purposes in such industries as steel, chemical, textiles, paper, and petroleum refining.

Integrated river basin management: The process of formulating and implementing a course of action involving natural, agricultural, and human resources of a river basin therewith taking into account the social, economic and institutional factors operating a river basin to achieve specific objectives. It signifies the interactions of components and the dominance of certain components in the particular area.

Intra-annual fluctuations: Fluctuation within a year.

Irrigation potential: Total possible area that can be brought under irrigation, in a river basin, region or country, from available water resources, with designs based on what may be considered as good technical practice known at the time of assessment of the potential.

Irrigation: The controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by precipitation.

Kharif: Crop season from June to September.

Land-use pattern: The area design or arrangement of land uses, major and minor, and of operation units convenient for cultivation.

Live storage: That part of the conservation storage of a reservoir which is between the full reservoir level and the level of the lowest outlet to be operated for delivering water for any use.

Mean annual precipitation: The average over a sufficiently long period of years of the annual amounts of precipitation so that nearly true representative value of the mean is obtained.

Mean annual rainfall: The mean of annual rainfall observed over a period, which is sufficiently long to produce a fairly representative mean value.

Micro-irrigation: A method of irrigation in which water is applied to the plants' root zone, in small but frequent quantities, in such a way as to maintain the most active part of the soil at a quasi-optimum moisture.

Natural Induced recharge: It is that portion of water, which gravitates to the zone of saturation under natural conditions. In the BHIWA model, a provision has been made for recharge from the river to the groundwater, either through natural or through forced recharge. The provision is to be made by the user for balancing the groundwater regime; user may also change the irrigation area etc. for using this provision.

Non-beneficial consumptive use: The water consumed

by native vegetation, evaporated from bare and idle land surfaces and from water surfaces.

Percolation – The movement of water through the openings in rock or soil.

Perennial: The crop period extends in three seasons throughout the year.

Potential evapo-transpiration (PET): The amount of water that could pass into the atmosphere by evapo-transpiration if the amount of soil water were not a limiting factor.

Potentially utilizable water resource (PUWR): The amount of the AWR that is potentially utilizable with technically, socially, environmentally, and economically feasible water development program.

Precipitation: The total measurable supply of water of all forms of falling moisture, including dew, rain, mist, snow, hail and sleet; usually expressed as depth of liquid water on a horizontal surface in a day, month, or year, and designated so daily, monthly or annual precipitation.

Quick run-off: That part of the rainfall, which flows into surface stream without passing through groundwater. As used in BHIWA, the term also includes the interflow.

Rabi: Crop season from October to January

Rain: Precipitation in the form of liquid water drops greater than 0.5 mm.

Rainfall intensity: The rate at which rainfall occurs expressed depth units per unit time. It is the ratio of the total amount of rain to the length of the period in which the rain falls.

Rain-fed: Crops which are grown on natural rainfall

Reference evapo-transpiration (ET_o): The evapotranspiration rate from a reference crop, not short of water is the reference evapotranspiration or reference evapotranspiration and is denoted as ET_o. The ET_o is climatic parameters and can be computed from weather data. ET_o expresses evaporating power of the atmosphere at a specific location and time of the year and does not consider crop characteristics and soil factors.

Replenishable groundwater: A dynamic groundwater potential available in aquifer.

Reservoir capacity, Gross capacity reservoir, Gross storage, or Storage capacity: The gross capacity of a reservoir from the riverbed up to the retention water level. It includes active, inactive and dead storages.

Return flow: The drainage water from a particular withdrawal that flows back into the system where it can be captured and reused, or recycled within the system.

Runoff: 1- Portion of the total precipitation from a given area that appears in natural or artificial surface streams. 2- Also the total quantity of runoff during a specified period. 3- The discharge of water in surface streams above a particular point. 3. Runoff is the surface and subsurface flow of water.

Salinity: The relative concentration of salts, usually sodium chloride in given water. It is usually expressed in terms of the number of parts per million of chlorine.

Soil moisture capacity: The capacity of the soil to hold the water within soil against gravitational force.

Steady state condition: In the BHIWA model, the condition in which, under average rainfall, the initial (beginning of first month) and final (end of last month) values of soil moisture and groundwater storages are the same, is described as a “steady state” situation.

Stream flow: The water discharge that occurs in a natural channel. A more general term than runoff, stream flow may be applied to discharge whether or not it is affected by diversion or regulation.

Subarid or Semi-arid: A term applied to an area or climate, neither strictly arid nor strictly humid, in which some selected crops can be grown without irrigation, According to Thornthwaite, areas having moisture index between (-)20 and (-)40 Thornthwaite moisture index are classified as semi arid areas.

Swamp: Wet spongy ground with fully saturated subsoil.

Taluka: A subdivision of a district

Transpiration: the emission or exhalation of watery vapour from the living plant.

Two seasonal: Crop period extending to seasons.

Water balance, or water budget: A systematic review or inflow, outflow and storage as applied to the computation of changes in the hydrologic cycle. Always referred to a specific time period like day, week, month, season or a year.

Water table: The upper surface of a zone of saturation, where the body of groundwater is not confined by an overlying impermeable formation.

